1974-06

An examination of alternative methods for employing booms to contain oil spills in Navy harbors.

Larson, Jerold Joseph

Monterey, California. Naval Postgraduate School

AN EXAMINATION OF ALTERNAIVE METHODS FOR EMPLOYING BOOMS TO CONTAIN OIL SPILLS IN NAVY HARBORS

Jerold Joseph Larson

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

AN EXAMINATION OF ALTERNATIVE METHODS
FOR EMPLOYING BOOMS TO CONTAIN
OIL SPILLS IN NAVY HARBORS

by

Jerold Joseph Larson

June 1974

Thesis Advisor: J. W. Creighton

Approved for public release; distribution unlimited.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) AN EXAMINATION OF ALTERNATIVE METHODS FOR EMPLOYING BOOMS TO CONTAIN OIL SPILLS IN NAVY HARBORS		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis June 1974
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s)		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE June 1974
		13. NUMBER OF PAGES 103
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Naval Postgraduate School Monterey, California 93940		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Booms
Oil Spill Containment Booms
Employing Oil Spill Containment Booms
Decision Analysis
Utility Analysis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In this thesis a plan is formulated which enables a decision maker to determine the relative effectiveness of three methods for employing oil spill containment boom. The evaluation is based on a utility analysis of three defined methods for employing oil spill containment boom. A decision analysis technique is employed to determine the relative importance

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
(Page 1) S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

of parameters indicating the utility of each method for boom employment. The plan provides a means for balancing cost considerations against potential benefits.

An Examination of Alternative Methods
for Employing Booms to Contain
Oil Spills in Navy Harbors

by

Jerold Joseph Larson
Commander, United States Navy
B.S., United States Naval Academy, 1958

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
June 1974

ABSTRACT

In this thesis a plan is formultated which enables a decision maker to determine the relative effectiveness of three methods for employing oil spill containment boom. The evaluation is based on a utility analysis of three defined methods for employing oil spill containment boom. A decision analysis technique is employed to determine the relative importance of parameters indicating the utility of each method for boom employment. The plan provides a means for balancing cost considerations against potential benefits.

TABLE OF CONTENTS

ACKNOWLEDGEMENT

The assistance rendered by Mr. Donald Brunner, of the Civil Engineering Laboratory, Mr. Robert Salazer of Alameda Naval Air Station and Commander Richard Fasig of the Eleventh Naval District Staff was invaluable in the preparation of this thesis and is herewith gratefully acknowledged.

I. INTRODUCTION

Man has been polluting the waters of the world for many years, but only recently has there been any concerted effort to curb pollution. Most everyone has heard of spreading oil on troubled waters, but this intentional pollution is not the principal concern. Rather, it is man's carelessness with contaminating effluents, such as petroleum products and industrial wastes, that has prompted concern and positive action to prevent pollution and clean up accidental spills. This study will address one portion of the pollution problem, methods of employing booms to contain oil spills in harbors controlled by the U.S. Navy. Containment of a spill is an essential step in the process of cleaning up a spill and reducing pollution.

A. OIL SPILLS OCCUR DESPITE PREVENTIVE MEASURES

Progress has been made in reducing the number of spills occurring and the volume of oil spilled. The U.S. Naval Ship Systems Command and many other organizations, civilian and military, are expending vast resources to eliminate or reduce the causes of oil spills. Throughout the United States almost 10,000 oil spill incidents are experienced annually and more than half of these occur in harbors or inland waters [1]. Examples of notable spills in recent years include: in 1967 S.S. TORREY CANYON ran aground and released over 200,000 tons of fuel, in 1969 off shore oil

rigs in the Santa Barbara, California channel released massive quantities of oil, in early 1973 over 120,000 gallons of oil from a storage tank were released into the Oakland, California harbor, and on December 29, 1973 over 16,000 gallons were released into the ocean and along the central California coast when U.S.N.S. PVT. JOSEPH MERRELL was damaged by a collision at sea. During 1972 the U.S. Navy reported 527 accidental oil spills, involving 116,221 gallons [2], and during 1973 reported 290 accidental oil spills, involving 53,151 gallons [3]. Of these Navy oil spills 98% occur in harbors and two percent in open ocean, but only five percent of the total volume is spilled in harbors and 95% of the total volume is spilled in open ocean [4]. It can be seen that Navy harbor spills are generally greater in number and of a smaller size than the open ocean spills. During 1972 and 1973, greater than 87% of all Navy spills were reported to have been of 200 gallons or less [2 and 3].

B. HOW OIL SPILLS ARE REMOVED

Left to itself, oil spilled into a body of water will eventually disappear. It will spread, evaporate, sink, disperse, emulsify and biologically degrade (microbial oxidation) [5 and 6]. Regretably man is releasing oil into the water faster than nature can remove it and the result is dirty harbors, ruined recreation beaches, reduced wildlife and biological death for some bodies of water [7]. Man is

now giving nature some assistance in the form of chemical and mechanical oil removal.

Chemical methods include: dispersing agents, sinking agents, emulsifiers, burning, and biological degradation enhancement. Dispersing, sinking and emulsifying don't really remove the oil, they simply make its effects more difficult to detect. Burning the oil off of the water's surface is feasible at times, if environmental conditions permit. Some success has been achieved with chemicals accelerating biological degradation, but no economically feasible process has yet been devised to isolate the enzymes providing this biodegradation enhancement [5 and 6]. The Environmental Protection Agency forbids the use of chemicals in cleaning up oil spills, except as specifically authorized by the EPA on a case by case basis. The possible adverse effects upon the environment by the chemicals themselves is feared [8].

Mechanical cleanup methods include: skimming, vacuum cleaning, absorption and beach scraping. All of these methods are acceptable to the EPA, since they physically remove the oil from the water. Numerous and varied devices have been developed to skim or vacuum the water surface. Some are self propelled and others are towed or stationary. Two basic absorption techniques are commonly employed: (1) an endless belt or series of discs rotate through the water, pick up oil, are squeezed out and then return to the water (oleophillic belts and discs), (2) absorption

materials, in the form of mats or small pieces (foam rubber, straw, saw dust, etc.), are spread onto the oily surface and then removed by various means. Beach scraping is at times looked upon as a failure, but it is an effective method and is used [5 and 6].

C. HOW OIL SPILLS ARE CONTAINED

After detecting an oil spill, one of the first steps in the cleanup process is containment. The configuration of some harbors provides a degree of natural containment. An enclosing breakwater, for example, can prevent an oil spill from escaping into navigable waters. Some chemicals have been developed which inhibit the natural spreading of oil. This is accomplished by spraying the periphery of the spill with the chemical, modifying the normal surface tension effects, and thereby greatly reducing the natural spread of the oil. As in the use of other chemicals to cleanup oil spills, the EPA prohibits their use for containing spills, except as expressly approved on a case basis. Again, the possible adverse effects upon the environment of the chemicals themselves is feared.

Mechanical measures remain the only universally accepted method of containment. Natural current flows provide a degree of containment in some harbors, but in general the currents only tend to spread and relocate an oil spill. Some success has been achieved with air curtains. In this method a pipe or hose, with small holes along the top side,

is laid along the harbor bottom and air is pumped through the pipe or hose. The air bubbles form a rising curtain, which wells outward at the surface, forming a barrier to surface flow. This method tends to be expensive, is effective only in very calm harbors, requires a constant supply of high pressure air and the holes in the pipe or hose can become clogged. However, this pneumatic barrier has some application and can be particularly effective as a gate to allow unimpeded waterborne traffic, when used in combination with a floating barrier [5].

Floating barriers, normally called booms, provide the most common method of containing an oil spill. Physically the boom provides a continuous barrier rising above the surface for a few inches, or as much as two feet, and extending below the surface for about one to six feet. The U.S. Navy has a military specification, MIL-B-28617(YD), which defines the requirements for three different booms varying in overall height from 13 inches to 36 inches. The three primary structural components of these booms are a floatation system, an oil containment barrier and a longitudinal strength member. The configuration and material from which the booms are constructed are as varied as the number of manufacturers competing for the market. The weights and costs per linear foot vary primarily with the materials used. Plastics, nylon, rubber and metals (for connection devices and strength members) are the materials most commonly encountered. Hundreds of booms are on the

market, with prices ranging from a few dollars to over fifty dollars per linear foot.

Oil spill containment boom may be deployed in a stationary manner or floating with the current and attended by boats. This later method is especially applicable to areas of high current, where a fixed boom could not contain a spill, but a boom moving with the current could contain a spill. Another method of boom employment is its use as a deflection device, used to divert a spill from an area of high potential damage.

Containment boom may be permanently installed as a precautionary measure, or it may be deployed after a spill occurs, in an emergency mode of operation. In the later case the boom may be stored in the water until a spill occurs, stored in containers on a nearby pier, or simply flaked down on deck.

D. OBJECTIVE OF THE STUDY

The objective of this study is to develop a plan for determining the most effective method of employing oil spill containment boom within the harbor facilities controlled by the U.S. Navy. After some study of the problem and considerable liaison with various naval activities the following methods for employing containment boom were defined:

METHOD I. The waters adjacent to all berthed ships is routinely enclosed with containment boom. A portion of this enclosement may be achieved with permanently installed boom and the remainder deployed as ships are berthed. That portion of boom deployed with each ship berthing may be stored in nearby waters or ashore.

METHOD II. All berthed ships conducting an external transfer of any potentially contaminating liquid are routinely encircled with containment boom. Generally, none of this boom is permanently installed, but is deployed from storage in nearby waters or ashore.

METHOD III. Containment boom is deployed only in the event of an actual spill of a contaminating liquid.

In defining these methods of boom employment the primary consideration is the circumstances under which boom is deployed. Secondary considerations include storage location of the boom and whether or not some portion of the boom is permanently installed. For ease of reference, Method I will be referred to as permanent booming, Method II will be referred to as transfer booming, and Method III contingency booming.

The Civil Engineering Laboratory (NCEL), Naval Construction Battalion Center, Port Hueneme, California has been tasked to determine the most effective method of boom employment. This tasking was part of an Advanced Development Objective (ADO No. 41-21, Harbor Oil Spill Removal/ Recovery Systems) issued by the Chief of Naval Operations on 6 March 1972. This tasking was passed to NCEL via the Naval Material and the Naval Facilities Engineering Command. In compliance with the ADO the Civil Engineering Laboratory has been employing its own research resources, in addition to evaluations being conducted by commercial research contractors. Because of the very close liaison maintained with NCEL personnel, it is anticipated that information similar to that appearing in this study will be included in a report

forthcoming from NCEL to the Naval Facilities Engineering Command.

E. THE NEED FOR DETERMINING THE MOST EFFECTIVE METHOD OF BOOM EMPLOYMENT IN NAVY CONTROLLED HARBORS

Various federal and state laws, presidential executive orders, and federal agency regulations have been issued in recent years restricting or prohibiting the discharge of contaminating effluents into navigable waters. The basic law is the "Federal Water Pollution Control Act" as amended by Public Law 92-500 of 18 October 1972. This law states the following national goals:

(1) it is the national goal that the discharge of pollutants into the navigable waters be eliminated by 1985;

(2) it is the national goal that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water be achieved by July 1, 1983;

(3) it is the national policy that the discharge of toxic pollutants in toxic amounts be prohibited;

(4) it is the national policy that Federal financial assistance be provided to construct publicly owned waste treatment works;

(5) it is the national policy that areawide waste treatment management planning processes be developed and implemented to assure adequate control of sources of pollutants in each state; and

(6) it is the national policy that a major research and demonstratoin effort be made to develop technology necessary to eliminate the discharge of pollutants into the navigable waters, waters of the contiguous zone, and the oceans. [9]

The U.S. Coast Guard and the Environmental Protection Agency have been tasked with the enforcement and

administration of water pollution control legislation. The EPA has provided criteria for acceptable effluent discharge, and in regard to oils the following standards have been established:

> Oils
>
> Concentrations of oil or petroleum products in marine or estuarine waters that exceed the limits described below are unacceptable.
>
> a. Detectable as a visible film, sheen, discoloration of the surface, or by odor;
>
> b. Causes tainting of fish or invertebrates or damage to the biota;
>
> c. Forms an oil deposit on the shores or bottom of the receiving body of water. [10]

The Coast Guard is guided by EPA regulations and the "National Oil and Hazardous Substances Pollution Contingency Plan" [11] in the discharge of its enforcement responsibilities. It also cooperates closely with various federal and state agencies, including the Department of Defense.

The U.S. Navy's basic directive for promulgating policy and assigning responsibility in the area of environmental protection is OPNAV INSTRUCTION 6240.3C(CH-1). This directive is in direct support of the nation's environmental protection goals, establishes a policy of leadership and accountability, provides guidance for the entire naval establishment and requires the submission of Oil/Hazardous Pollution Substance Reports.

The Chief of Naval Material, among other things, has been assigned the responsibility of identifying and evaluating systems and equipments affecting environmental quality

within the Navy, developing material requirements in support of environmental protection, and providing advice and assistance to other naval commands on environmental quality matters [12]. The Naval Material Command assigned the Naval Facilities Engineering Command (NAVFAC) the overall technical responsibility for determining the oil spill equipment requirements of naval activities [13]. Before determining oil spill cleanup equipment requirements, methods for employing this equipment must be established. As mentioned earlier NAVFAC has passed this task to the Naval Civil Engineering Laboratory. This study will confine itself to that portion of the problem concerning oil spill containment equipment (e.g. booms).

Preliminary estimates indicate that during the next six years (FY 74-79) the Navy will spend over 39 million dollars for oil spill control equipment to be used in harbors, and of this amount nearly nine million dollars will be spent on containment equipment alone [14]. These figures include capital investment values only, and do not include the costs of operation or maintenance, which could be considerable. In examining methods for the employment of oil spill containment equipment, cost will be a major consideration, however many other factors impact on the problem. These factors include: (1) potential damage of uncontained spills (liability, as well as, real and aesthetic damage to the environment), (2) degree of compliance with regulations to prevent oil spills from entering navigable waters,

(3) degree of convenience afforded normal harbor operations, (4) public affairs impact of oil spill containment efforts made by the Navy. On 27 November 1973 the EPA modified part 112, subchapter D, Chapter I, Title 40, Code of Federal Regulations. This modification, among other things, states,

> 112.7 (c) Appropriate containment and/or diversionary structures or equipment to prevent discharged oil from reaching a navigable water course should be provided. One of the following preventive systems or its equivalent should be used as a minimum: . . .
>
> (iv) Weirs, booms, or other barriers . . .
>
> (d) When it is determined that the installation of structures or equipment listed in section 112.7(c) to prevent discharged oil from reaching the navigable waters is not practicable from any onshore or offshore facility, the owner or operator should clearly demonstrate such impracticability. . . . [15]

The need for this study is clear and rather pressing. Procurement action to obtain oil spill containment equipment for use in Navy controlled harbors must go forward. A sound procurement plan depends, in part, on a determination of the method for employing oil spill containment boom in each Navy controlled harbor.

II. BACKGROUND

A. HISTORICAL REVIEW

The oceans of the world impress everyone with their size and timelessness. For all of recorded history their size, and to a major degree their appearance, has remained virtually unchanged. Yet, life in the oceans is changing every day, and in recent years these changes have been noted at an increasing rate. Some portion of the world's human population has long depended upon the oceans for food, salt, clothing and transportation. Additionally, through technical advances in the process of desalinization, man has recently begun to depend upon the oceans as a source of fresh water.

The effects of pollution upon the waters of the world are both blatent and subtle. The blatent effects are as obvious as a dirty port, oily sand on a recreation beach, or poisoned marine life. The more subtle effects, such as the disruption of the natural food chains, are under intensive study. It is known that almost all marine life ultimately depends on phytoplankton and zooplankton for food. As a first step in many food chains of the oceans the planktons represent the source of the sea life which man harvests. Unfortunately, it is not yet known how adverse the effects of oil will be on plankton populations, but it is known that the food chains are being altered by oil and other contaminating substances. Studies conducted in the

Peru Current of the Pacific Ocean have provided some insight into effects of disrupting basic food chains [16].

Some scientists believe that the present ecological state of the Mediterranean Sea foretells the ultimate fate of other oceans. Homer referred to the Mediterranean as being "fish-infested" and today fewer than 1.1 million metric tons of fish are taken from this body of water each year, while the worldwide take is over 50 million metric tons. More than 4300 miles of Italy's 5000 mile coast are polluted to a point that shellfish taken there are unsafe for human consumption. French oceanographers Dr. Alain Bombard and Jaques-Yves Cousteau, among others, give the Mediterranean less than 25 years before it is totally biologically dead [7].

The adverse environmental impact of pollution, including oil pollution, upon the waters of the world is also reflected in economic terms. In addition to the food, tourist trade and aesthetic losses (e.g. wild life, dirty harbors, recreation), there are tremendous resources expended just in cleaning up oil spills. The cost of correcting the damage caused by the S.S. TORREY CANYON spill was in excess of $8 million, the 1973 Oakland harbor spill $1.5 million and the 1973 USNS PVT. JOSEPH MERRELL spill in excess of $400,000. Additionally, there are over a hundred cooperative oil spill cleanup organizations in the United States alone, some of which have annual operating budgets in the millions of dollars [17]. All of this in addition to the expenditures by agencies of the federal and state governments.

B. REVIEW OF RESEARCH PREVIOUSLY CONDUCTED

1. Behavior of Oil Spills on Water

Relatively little information is available in the literature on the behavior of large oil spills on water. This is due, in part, to the adverse public opinion which would result from an intentional experimental discharge of oil. Some laboratory and small scale field experiments have been conducted, however [5, 18 and 19].

One group investigated the spreading rates of several crude oils with specific gravities of 0.829 to 0.896. These experiments indicated that the thickness of an oil slick gradually reduced as the area increased, until the thickness reached 0.02 MM to 0.03 MM (0.0008 in. to 0.0012 in.) [5]. Other experiments, using medicinal oils and pure water, have resulted in film thicknesses of 0.0003 MM and thinner, while ordinary industrial oils in contaminated water may result in a final film thickness of 1 MM [18]. These studies deal with unconfined oil spills, and it should be noted that a contained spill may result in the oil film building to a thickness in excess of an inch (25.4 MM).

A relationship for slick thickness versus time may be expressed:

$$\text{slick thickness (cm)} = k/t^{2/3}$$

where:

$$k = (v/\pi)^{1/3} \left[\frac{dw}{3do(dw-do)\ Kr}\right]^{2/3}$$

v = volume of oil (cm^3)

$\pi = 3.14$

do = density of oil (g/cm^3)

dw = density of water (g/cm^3)

Kr = a constant for a given oil

It can be seen that the tendency for an oil spill to expand is due, in part, to the difference in densities of the oil and water. In the case of some common heavy petroleum products this difference approaches zero, as does the spreading force [5].

The spread rate is approximately proportional to the mean layer thickness of the oil. When a spill initially occurs the spreading from a very thick layer to about 2 cm takes so little time that it has been omitted from experiments. For example, a spill of over 26,000 gallons of oil spread to a 2 cm thickness in about one minute. For layer thicknesses of about 2 cm and less the formula provided above may be used to determine rates of oil spread [5 and 18].

It has been found that the pour point of the oil has a decided effect on the rate of spread. If the pour point is greater than the existing temperature of the water, there will be little tendency for the oil to spread. This is especially true if the specific gravity is close to that of water [18]. In this case the oil would tend to form into amorphous masses. These "tar balls" are a common nuisance in the aftermath of spills involving heavier oils. For some time it was believed that viscosity had a significant effect on oil spreading rates, but it has since been determined that this is not the case. The effect of viscosity is now

considered negligible [18 and 19]. Other factors having small effect on the rate of spread include: surface tension, interfacial tension between oil and water, chemical composition and environmental conditions [5].

As an oil slick spreads some degree of evaporation is occurring simultaneously. Initially layer thickness decreases primarily as a result of spreading, but as the layer becomes thinner and increases in area the influence of evaporation becomes greater. Lighter, more volatile, fractions of the oil evaporate quickly and leave behind the heavier fractions. The danger of fire usually exists for a matter of minutes, and even with gasolines the danger is past after an hour. However, if there is debris in the water to act as a wick the danger of fire may persist for two or three hours [18].

In addition to the movement of an oil slick caused by spreading, environmental forces act upon the slick. The effect of currents are direct and easily understood. In the absence of other forces, the slick will move at the same velocity as the surface water current [5].

The effects of wind are not so intuitively understandable. The movement of a slick because of wind may vary with spill size, water temperature, water depth, salinity, wave height and the amount of debris in the water [20]. In general, observations have shown that an oil slick will move at about three to four percent of the wind's velocity, with most observations falling between 3.3% and 3.7% [5

and 20]. It has been determined that the velocity of an oil slick decreases as wave action increases. This is because the water in a wave moves vertically, but has little lateral movement, and while the oil is in the lee of a wave crest it is not acted upon by the wind. It is difficult to separate the effects of wind and waves since the wave height depends primarily upon the wind [20]. The important observation here is that an oil slick can be expected to move at three to four percent of the wind's velocity. The combined effects of spreading, current and wind must all be considered in determining the behavior of an oil spill on water.

2. Oil Spill Containment Boom Hydrodynamics

Oil spill containment booms are commercially available in a wide variety of sizes and configurations and are manufactured from a number of materials. The prime attribute of any boom is that it must present an unbroken barrier at the surface of the water. It must also extend above and below the water's surface sufficiently so that oil can neither splash over the boom nor slip under it. The boom must be durable so it will withstand currents, waves and weather, yet it must be flexible enough to ride the surface and conform with the vertical movement of the water, sometimes called dynamic pitch response.

Oil escapes booms via three mechanisms. First, the oil splashes over the top, or the boom submerges sufficiently to allow oil to flow over it. Next, as an oil slick collects against the boom's surface it becomes thicker. If the slick becomes thick enough it will slip under the boom,

and this loss mechanism is known as drainage. Drainage is aggravated when a boom agitates the water with rapid vertical movement. Finally, a boom may fail to contain a spill as a result of entrainment. Entrainment occurs at the upstream portion of the slick, away from the boom. When the water current flowing under the slick is fast enough, small drops of oil submerge and are carried with the current under the slick and the boom, and then eventually resurface downstream of the boom [21, 22, and 23].

Although various factors (e.g. oil density, pour point, interfacial tension, relative current velocity, wind velocity, temperature, boom size and configuration) effect a boom's ability to contain a spill, relative current velocity and wave height have the greatest effects. Considering oils one might normally expect to find in a Navy harbor, moderate weather conditions and a boom with a two foot skirt depth, entrainment losses could begin at a relative current velocity of 0.4 knots [23] and become severe at about 1.0 knot [21]. Under these same conditions drainage losses would occur at velocities of one to two knots. The boom depth required to preclude drainage losses increases approximately with the square of the current velocity. Some experiments indicate that for a two foot skirt depth and an oil with 0.95 specific gravity, drainage failure will occur at about one knot. This means that a boom depth of about eight feet would be required to prevent drainage failure in a two knot current [23]. It can be seen that booms capable

of containing spills in currents much above one knot soon become unmanagably large. The Navy's specifications for harbor booms do not indicate a boom with a skirt depth greater than 24 inches [24].

3. Studies of Oil Spill Cleanup Technology

Numerous studies investigating oil spill cleanup equipment and technology have been conducted by various agencies. The U.S. Coast Guard and Navy have conducted or funded many of these investigations. In some cases consulting or research firms have been contracted to conduct the studies.

A study conducted by Arthur D. Little, Incorporated for the Coast Guard in 1969 is often noted as a basic reference in oil spill pollution control. The report of this study provides information on the state-of-the-art of available methods for combating oil spills and basic technology in the field. It discusses oil on water behavior, methodology, equipment, economic considerations and identifies areas for further research. The report treats both harbor and open ocean oil spill cleanup techniques [6].

In 1969 the Naval Civil Engineering Laboratory and the Naval Facilities Engineering Command commissioned the Battelle Memorial Institute of Richland, Washington to conduct a study of equipment and methods for removing oil from harbor waters. The report of this study discusses characteristics of oil spills, harbor conditions in ten harbors used by the Navy, methods for determining oil spill cleanup

effectiveness and methods for selecting cleanup systems. It also provides cost estimates for equipment available in the commercial market [5].

In 1970 Battelle Pacific Northwest Laboratories conducted a study of equipment and methods for removing or dispersing oil from open waters for the Supervisor of Salvage, U.S. Naval Ship Systems Command. Although this study was concerned primarily with open ocean oil spills, it did contain useful background information suitable for harbor application. The equipment and methodology used in open ocean differs from those used in harbors in that equipment must be larger, capable of withstanding more severe environmental conditions and being air transportable [25].

A 1973 study conducted by Battelle Columbus Laboratories for the Naval Civil Engineering Laboratory evaluated oil spill recovery systems for use in a harbor environment. This study examined various booms, skimmers, storage devices and oil/water separators. The evaluations were carried out in test tanks and harbors, using small oil spills. The results of this evaluation will provide guidance for the Naval Facilities Engineering Command in subsequent equipment procurement actions [26].

Six oil containment subsystems (booms) were evaluated by Battelle Pacific Northwest Laboratories for the Naval Civil Engineering Laboratory in 1973. Based on previous studies of the containment problem, six leading boom manufacturers were requested to provide booms for evaluation. The

booms were tested to determine their durability, maintainability, containment capability, mobility and tensile strength. This study will also assist the Naval Facilities Engineering Command in determining criteria for purchasing containment booms [27].

4. Technology Transfer

Effective technology transfer in the area of oil spill cleanup is of considerable importance. Duplication of research can be very costly and wasteful. Within the Navy Material Command technology is transferred between the Naval Facilities Engineering Command and the Naval Ship Systems Command, and their various research organizations, by a transfer of reports and discussions.

Various conferences are conducted periodically to exchange information and technology. The American Petroleum Institute conducts yearly conferences on oil spill cleanup. These conferences are attended by various representatives of the petroleum industry, as well as the academic community, the U.S. Navy, the U.S. Coast Guard and the EPA. The Navy also conducted a conference on oil spill control, 1-4 May 1972. The U.S. Navy Supervisor of Salvage conducts an informal training course semiannually to exchange technology in the area of oil spill cleanup. Occasionally an international harbor conference is conducted. The papers presented at these conferences and the published proceedings are invaluable current references.

Collections of reference material are maintained by various state and federal agencies. For the Navy's purposes two are significant: The Defense Documentation Center and the library at the Naval Civil Engineering Laboratory.

5. Availability of Oil Spill and Cleanup Cost Data

In April 1971, the Chief of Naval Material directed the Naval Facilities Engineering Command to assume responsibility for the maintenance of an Environmental Protection Data Base (NEPDB). The Naval Civil Engineering Laboratory (NCEL) was in turn designated the deputy program manager for this project. In support of the project a Navy Environmental Support Office (NESO) was established at NCEL. As one of its responsibilities the NESO maintains a computer supported data bank on all oil spills from U.S. Navy ships, aircraft, shore stations and any other spills occurring within Navy controlled harbors. All Navy ships, aircraft and stations have been directed to include the NCEL as an addressee on Consolidated Oil/Hazardous Pollution Substance Reports [12]. Data from that source has been examined in order to gain an overview of the problem addressed in this study.

Appendix A is a linear regression analysis of the oil spills reported to the NESO for the 24 months of 1972 and 1973. The regression analysis technique is just one method of predicting the future based on past events. The simple linear equation derived in the regression analysis fit the reported oil spill data quite well and an examination of the time sequence plot of residuals also indicates that the linear equation is reasonably accurate [28]. This analysis

indicates that the number of reported Navy oil spills is decreasing at a rate of about 1.8 spills per month and that the number of spills reported is rapidly approaching zero.

Data provided by the Environmental Protection Officer (code Ø3E) on the staff of the Commandant Eleventh Naval District shows that the number of observed oil spills at Naval activities in San Diego harbor varies somewhat from month to month, but that it has been nearly constant, or slightly increasing, during the 24 months of 1972 and 1973. Comparison of the data from NESO and COMELEVEN shows that while NESO received reports indicating that 30 spills occurred in San Diego during 1973, COMELEVEN indicates that 174 spills were observed and cleaned up at San Diego during 1973. This discrepancy in data is even more pronounced when the following is observed:

MONTH 1973	NAVY-WIDE OIL SPILLS REPORTED TO NESO	OIL SPILLS OBSERVED AND CLEANED UP AT NAVAL ACTIVITIES IN SAN DIEGO
JUL	23	13
AUG	14	17*
SEP	11	17*
OCT	19	20*
NOV	27	13
DEC	12	17*

During four of the last six months of 1973 COMELEVEN records indicate that more oil spills were observed and cleaned up in San Diego alone than NESO data indicates occurred in the entire Navy from all sources. Obviously all oil spills are

not being reported to NESO by the originators of the spills. Spot checks of other naval activities indicate similar discrepancies may exist between the numbers of observed and reported oil spills.

In conducting this study it was necessary to contact individual naval activities in order to determine the number of spills cleaned up. Cost data is not included in the Consolidated Oil/Hazardous Pollution Substance Reports submitted to NESO. Therefore, individual activities also had to be contacted in order to determine cleanup costs. In accordance with chapter four, volume two of the Navy Comptroller Manual (NAVSO P-1000-2) oil spill cleanup costs are charged against cost account code 6F80 (Oil Spillage Cleanup) and reported to cognizant type commanders. The type commanders do not forward this information to the fleet commanders, the major claimants, however. The major claimants prefer to have this information condensed into the summary cost account 6E00, port services. Therefore, under the present cost accounting system the cost data for oil spill cleanup operations is not identifiable at the fleet or Navy headquarters level. This lack of data within the existing cost accounting system makes studies of this nature more difficult, and could be a source of some embarrassment to the Navy if an outside agency were to ask for it.

III. THE APPROACH USED IN DEVELOPING A PLAN FOR DETERMINING THE MOST EFFECTIVE METHOD OF EMPLOYING CONTAINMENT BOOMS IN NAVY HARBORS

A. DETERMINING THE SCOPE OF THE PROBLEM

In defining the problem and determining its scope, the literature research indicated in the previous two sections was conducted. But, it was also necessary to discuss the problem with various federal, state and private agencies. This investigation helped to uncover even more literature on related subjects.

1. Naval Activities

Some research has been conducted by the students and faculty of the Naval Postgraduate School. Discussions with several faculty members provided useful information and leads to other sources. Four visits and many telephone conversations were conducted with the staff of the Naval Civil Engineering Laboratory. Since the Naval Facilities Engineering Command had tasked NCEL with the problem addressed in this study, and since NCEL had already conducted significant research on this and related problems, the NCEL staff was in a position to provide considerable information. Liaison, in the form of visits and telephone calls, was also conducted with the Naval Facilities Engineering Command, the Naval Ship Systems Command, the Office of the Comptroller of the Navy, the Office of the Chief of Naval Operations (OP-45), Naval district staffs, fleet commander's staffs, type commander's staffs and numerous naval activities.

2. Federal and State Agencies

Liaison was conducted with the U.S. Coast Guard Pacific Strike Team, USCG Port Captain of Monterey, the San Francisco office of the EPA, and the California Resources Agency.

3. Private Agencies

Several private companies that manufacture and/or sell cleanup equipment or contract for cleanup services were contacted, as were two oil spill cleanup cooperatives. The cooperatives were formed by private industries, which by the nature of their business have a vested interested in preventing and cleaning up oil spills. Visits were made to two private marine terminals to investigate their methods for oil spill containment.

Private contractors and cooperatives have some advantages over the Navy, in that their cleanup personnel and equipment are more efficiently employed. They have an opportunity to regularly employ their services, thereby making the utilization of equipment more efficient, and developing a degree of expertise among their personnel. Some contractors sell a permanent containment system and guarantee the cleanup of oil spills within the system. Buyers of these systems are pleased with the results and are convinced that the permanent system has paid for itself in reduced cleanup costs, not to mention the reduced damage liability, fines, court costs, and improved public relations.

B. THE INITIAL APPROACH TO SOLVING THE PROBLEM

The initial approach to the problem was an effort to determine the most cost effective method of boom employment to be used in Navy controlled harbors as a group. Or, as an alternative, to determine the most effective method for each of several classes of naval activity. Naval activities could be classified by size, number or type of ships operating, number of spills occurring, type of activity (e.g. shipyard, naval station bulk fuel station), etc. With some guidance from personnel at NCFL, who had worked on similar problems, three classes of naval activity were selected: bulk fuel depots, large naval stations/shipyards, and small naval stations/shipyards.

Appendix B is a questionnaire (fact sheet) that was forwarded, in February 1974, by NCEL to 26 major naval activities having port operations and a potential for oil spills. Twenty-two activities (85%) responded to the questionnaire and the results were examined. It soon became clear that the factors to be considered in an effectiveness analysis (i.e. number of ships operating, number of spills experienced, environmental factors, etc.) varied widely from one activity to the next, and there was no valid method of classifying naval activities, and finally that each naval activity would have to be considered individually when determining the most effective method of employing containment boom.

C. COST EFFECTIVENESS STUDY

The approach taken at this point was to develop a plan that could be utilized for each activity in determining the relative cost effectiveness for each of the three methods of employing containment boom [29 and 30]. Determining the cost of each method requires information such as the cost of boom, feet of boom required, installation costs, number of ship berthings, number of fuel transfers, cost to open and close a permanent boom, number of spills predicted, etc. All of these can be measured, determined by bids, an analysis of historical data, or estimates.

Parameters to determine effectiveness present some problems, however. The parameters tend to be rather subjective and no valid method for weighting the parameters could be determined. Further, to base decisions on a ratio of cost to effectiveness requires the acceptance of the premise that cost and effectiveness are equally weighted. For example consider the following:

$$\frac{\text{Cost}}{\text{Effectiveness}} \qquad \underline{\text{Plan A}}\ \ \frac{100}{10} = 10 \qquad \underline{\text{Plan B}}\ \ \frac{200}{10} = 20$$

By doubling cost in Plan A <u>or</u> halving effectiveness in Plan A,

$$\underline{\text{Plan A}}\ \ \frac{200}{10} = 20 \qquad \text{or} \qquad \underline{\text{Plan A}}\ \ \frac{100}{5} = 20$$

Plan A achieves a cost effectiveness ratio equal to that of Plan B, because cost and effectiveness are considered equally important. However, this may not be the manner in which

these two considerations are really valued. It was therefore determined that a plan employing a utility analysis technique would produce more valid criteria and be of greater value to the decision maker.

D. UTILITY ANALYSIS

The heart of a utility analysis is the assignment of a measure of "goodness" (or "badness") to all possible future outcomes resulting from decisions made now. This measure, called a utility, is a number between zero and one, with the value "one" representing the most desirable and "zero" the least desirable possible outcomes. The utility measure is constructed in such a way that, if uncertainty is present, expected utility is a valid decision criterion. That is, suppose a particular decision can lead to any of a number of different outcomes [31]. If one can determine the utility of each possible outcome and make an educated guess at the chances of each outcome occurring, then one can easily compute an expected utility for that decision, which effectively summarizes both the attractiveness and the probability of each possible outcome [32].

In summary, utility analysis has the following advantages:

1. A measure of "goodness" or "badness" can be determined for each possible outcome. Dollar costs would, of course, be an important part of this measure.
2. The utility thus defined can be used even under conditions of uncertainty.

IV. DEVELOPMENT OF A UTILITY ANALYSIS PLAN FOR DETERMINING THE MOST EFFECTIVE METHOD OF EMPLOYING CONTAINMENT BOOMS IN NAVY HARBORS

A. DECISION ANALYSIS THEORY

In this problem, the utility, or measure of goodness, valid for all possible outcomes must be determined. To do this, the following result from the field of multidimensional utility was used. Suppose consequences were measured in terms of n different attributes, and let $\underline{x} = (x_1, x_2, ---, x_n)$ denote a particular consequence. A utility function over $\underline{x}$ is denoted as $U(\underline{x})$. Now consider any two of the attributes, say x_i and x_j, and look at any two values for each of those attributes, say ${}^1x_i$, ${}^2x_i$, ${}^1x_j$, ${}^2x_j$. Then if the decision maker finds both the gambles

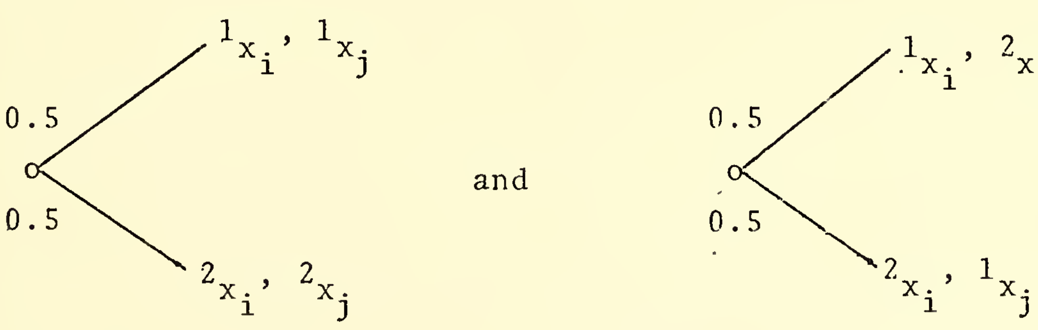


Figure I

equally attractive (or unattractive), and if this is true for all possible pairs of x_i and x_j, then one can express $U(\underline{x})$ as

$$U(\underline{x}) = k_1u_1(x_1) + k_2u_2(x_2) + \dots + k_nu_n(x_n) \quad (1)$$

where the k_i are constants between zero and one, and the $u_i(x_i)$ are utility functions over each of the attributes x_i, $i = 1,\dots,n$. In this problem the requisite assumptions were verified, and the utility function was assumed to have the form indicated in equation (1) above [32].

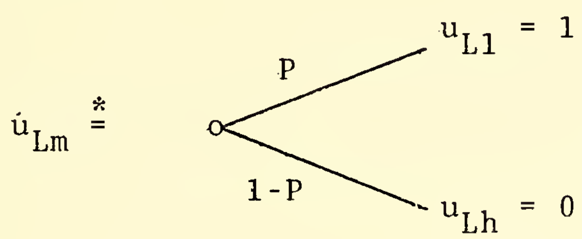
B. DEFINITION OF PARAMETERS AND DETERMINATION OF PARAMETER UTILITY

In determining the utility for each method of boom employment, five considerations were determined to be of major importance. These parameters are discussed in order of relative importance below.

1. Liability

This parameter (L) indicates the liability that the Navy might incur as the result of an uncontained spill. This includes damage suits and fines that might be handed down from federal, state and local courts. It is highly unlikely that a federal court would fine the Navy, but it is certainly possible that state and local courts might [33 and 34]. The Navy has generally avoided damage suits by taking action to correct any damage resulting from spills for which it might be found liable. Also included in this definition of liability is some consideration of the overall environmental impact resulting from a spill. For the purposes of this analysis three possible levels of liability were defined. Potential for liability would be evaluated as high if an uncontained oil spill could result in significant damage to a major boat

marina, recreation beach, wildlife refuge, etc. Medium liability would indicate that an uncontained spill could result in minor damage to a small boat marina, a seldom frequented shore or a wildlife area, while potential for liability would be evaluated as "low" if an uncontained spill would not result in any significant damage to property, wildlife or the environment. A utility value of zero was placed on high liability (L_h) and a utility value of one on low liability (L_1). In order to determine a utility value for medium liability (L_m) a decision fork, or gamble, between high, medium and low liability was considered:



where: u_{Lh} = utility of high liability

u_{Lm} = utility of medium liability

u_{L1} = utility of low liability

P = probability of low liability

$\stackrel{*}{=}$ = indicates indifference

A value for the probability of low liability (P) now had to be determined such that if a spill is assumed to occur under conditions such that no containment is possible, the decision maker would be indifferent to being guaranteed that medium liability (L_m) would result or would accept a gamble of some probability, P, that there would be low liability (L_1) and some probability, 1-P, that there would be high liability (L_h).

Acting for the decision maker, it was determined that P would have to equal 0.6 in order to be indifferent to the gamble. This means that the decision maker would be indifferent to a guarantee of medium liability or taking a gamble that 60% of the time liability would be low and 40% of the time liability would be high. It should be noted that the decision maker evaluating this indifference gamble would be doing so for the entire Navy. Based on P of 0.6 we find the utility value for medium liability:

$$u_{Ll}\ (P) + u_{Lh}\ (1-P) = u_{Lm}$$

$$1\ (0.6) + 0\ (0.4) = 0.6$$

The following utility table is indicated:

Liability	L_h	L_m	L_l
Utility (u_L)	0	0.6	1

When considering the potential for liability, it is assumed that a spill occurs and is not contained prior to entering navigable waters. Under these conditions it can be seen that the potential for liability will be dependent upon the activity (or harbor) under consideration, but independent of the method of boom employment.

At some activities the potential for liability may vary with the existing conditions at the time of the spill, such as state of tide, current, wind, time of day, etc. Therefore, at each activity a determination must be made regarding the probability for high, medium or low liability. That is, assuming a spill is not contained, what is the

probability that high, medium and low liability will result? Symbols for these probabilities are:

Probability of high liability: aL_h

Probability of medium liability: bL_m

Probability of low liability: cL_l.

2. <u>Probability of an Uncontained Oil Spill</u>

This is the probability that given a spill occurs, it will be uncontained and enter navigable waters. EPA regulations prohibit allowing this to happen, it is also contrary to Navy policy, and if this does happen the Navy may experience liability, increased cleanup costs and bad public relations. The EPA regulations, and the Navy directive ordering that these regulations be complied with, require that "appropriate containment" equipment be provided "to prevent discharged oil from reaching navigable waters" [15]. But, the extent to which an activity must proceed to in order to provide "appropriate containment" is not precise. In order to continue this analysis it was assumed that appropriate containment would provide for preventing something in excess of 90% of all spills from entering navigable waters, or, that the maximum allowable probability of a spill entering navigable waters, was 0.1. Because this is the maximum allowable probability it was assigned a minimum utility of zero, and the probability that no spills would enter navigable waters was assigned a utility of one. A curve was developed (Figure II) for points between a utility (u_p) of zero and

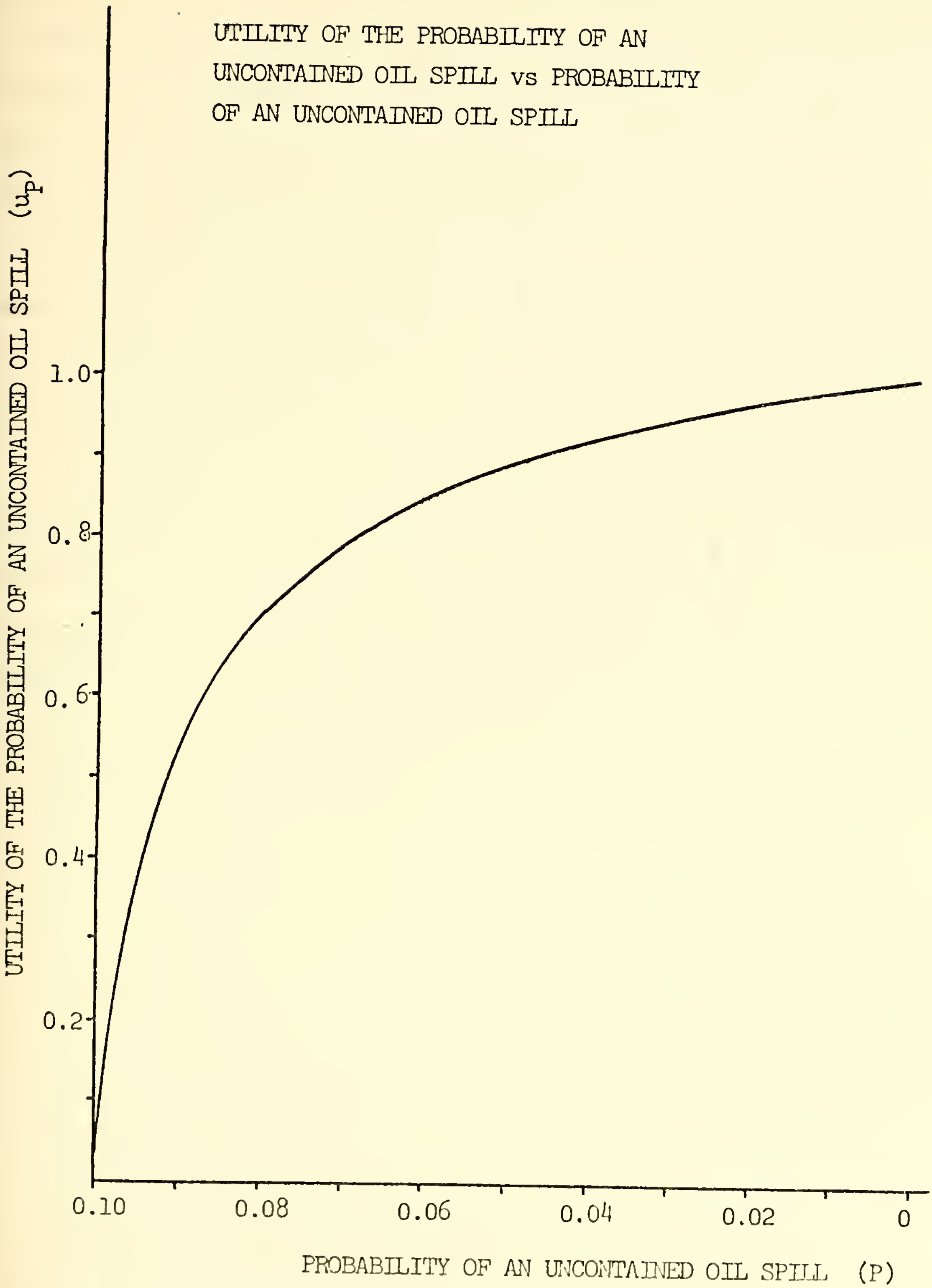

UTILITY OF THE PROBABILITY OF AN
UNCONTAINED OIL SPILL vs PROBABILITY
OF AN UNCONTAINED OIL SPILL
UTILITY OF THE PROBABILITY OF AN UNCONTAINED OIL SPILL (u_p)
1.0
0.8
0.6
0.4
0.2
0.10
0.08
0.06
0.04
0.02
0
PROBABILITY OF AN UNCONTAINED OIL SPILL (P)

Figure II

one by using a decision fork, technique similar to that used in determining the utility of medium liability above. As might be expected this function is not linear. It was found that greater utility was derived from improving the probability of a spill entering navigable waters from 0.10 to 0.09 than from 0.01 to 0.00. Inspection of the curve indicates that meeting the bare minimum provides zero utility and that utility increases as the probability of a spill entering navigable water decreases, but at a decreasing rate.

The value of this utility parameter will depend both upon the harbor under consideration and the method of boom employment. The probability of a spill being uncontained and entering navigable waters can be evaluated for each method of boom employment, by ascertaining three probabilities for each port and using the following technique:

Method I. The probability that permanent boom (Method I) will contain a spill and prevent it from entering navigable waters is "s," and the probability that Method I alone will allow a spill to enter navigable water is "1-s." It is assumed that some portable boom will be available to contain spills outside a permanent boom or to capture spills escaping the permanent boom. In event of this type contingency, the probability that portable boom can capture a spill before it enters navigable water is "m,", and the probability that the spill cannot be contained by the portable boom prior to entering navigable water

is "1-m." When using Method I, backed up by contingency portable boom, the probability of a spill being uncontained and entering navigable water is:

$P_I = (1-s)\ (1-m)$

Method II. The probability that a spill occurs during an external fuel transfer, and would therefore be encircled by containment boom when using Method II is "r," and the probability that a spill occurs when a ship is not encircled with containment boom is "1-r." When using Method II, again backed up by contingency portable boom, the probability of spill being uncontained and entering navigable water is:

$P_{II} = [(1-r) + r(1-s)]\ (1-m)$

Method III. The probability that a spill will be uncontained and enter navigable water when using only contingency boom is: $P_{III} = (1-m)$

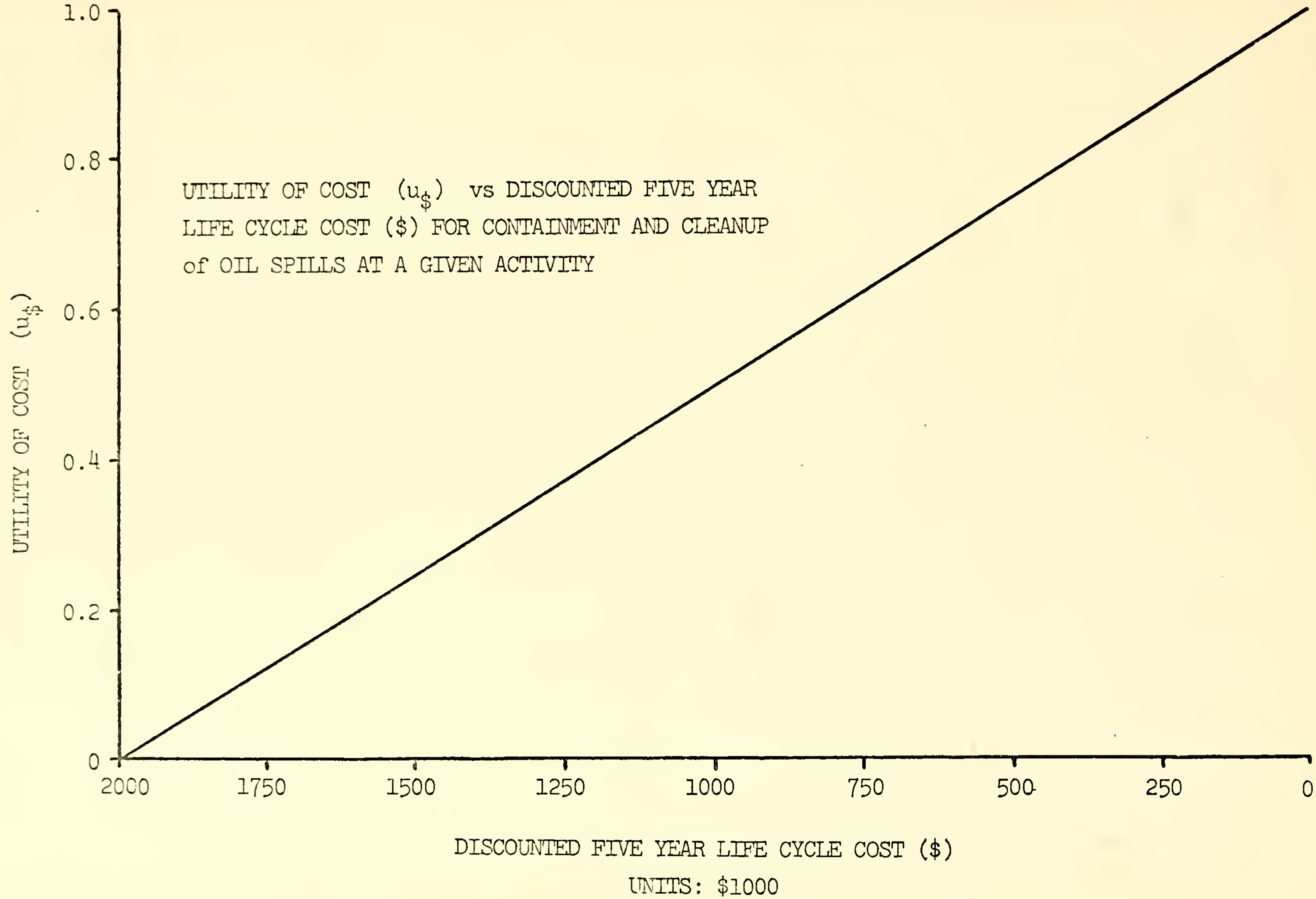
3. Cost

The cost parameter ($) for each method of boom employment includes the dollar value of all expected expenditures for both containment and cleanup of oil spills in any given Navy harbor. Since containment boom may last for more than a year, some are guaranteed for up to five years, life cycle costing should be employed. The time value of money should also be considered and the standard DOD discount rate of ten percent be applied [35].

Although the utility of cost ($u_\$$) must be determined for each method of boom employment at each naval activity, the utility of cost function should be a Navy-wide parameter. That is, one function of cost utility should be determined at the Navy headquarters level and then applied to each activity. Since this function is expressing the utility of cost for the entire Navy, and since the Navy budget is very large in comparison to the oil spill containment and cleanup costs involved, this function is assumed to be a linear relationship. It is of little concern to the Navy whether the cost is incurred at one naval activity or another, the utility of cost is the same at each Naval station. Likewise a cost differential at the high or the low end of the range is of little consequence, it is the size of the differential at each activity that is of concern.

In order to proceed with the utility analysis plan a utility of cost function was developed (Figure III). The upper end of the cost scale was established at $2 million. This was determined to be the maximum five year life cycle cost, discounted for the present value of money, which would be experienced by even the largest and most active naval stations, using the most costly method of boom employment. The lower end of the cost scale was established at a theoretical zero cost. A maximum utility (1.0) occurs at zero cost and a minimum utility (zero) at the maximum cost. The cost experienced will depend upon the harbor under consideration and the method of boom employment utilized.

Figure III


UTILITY OF COST ($u_\$$) vs DISCOUNTED FIVE YEAR
LIFE CYCLE COST ($) FOR CONTAINMENT AND CLEANUP
of OIL SPILLS AT A GIVEN ACTIVITY
1.0
0.8
0.6
0.4
0.2
0
UTILITY OF COST ($u_\$$)
2000
1750
1500
1250
1000
750
500
250
0
DISCOUNTED FIVE YEAR LIFE CYCLE COST ($)
UNITS: $1000

4. Convenience

The convenience parameter (C) expresses the degree of non-interference or convinience afforded to normal Navy ship and craft operations within a given harbor. Two discrete values of utility have been selected for the utility of convenience (u_C): "reasonably convenient" having a utility value of one and "inconvenient" having a utility value of zero. The value of this parameter will depend upon the harbor under consideration and the method of boom employment. Therefore a determination of relative convenience will be required for each method of boom employment.

Convenience	u_C
Reasonably Convenient	1
Inconvenient	0

5. Public Affairs

The public affairs parameter (PA) reflects the Navy's public image, or public relations, and the utility (u_{PA}) associated with good or bad public affairs resulting from oil spill containment, preventive action and corrective action. Although public affairs in this area is somewhat related to liability, it can be considered a separate parameter since liability and public relations are not always perfectly correlated. In determining the utility of public affairs two discrete values were selected: "good" public affairs having a utility of one and "bad" public affairs having a utility of zero.

Public Affairs (PA)	Utility (u_{PA})
Good	1
Bad	0

Since public affairs may be related to the method of boom employment, the liability incurred if a spill is uncontained, and the existing public affairs environment, it would be appropriate for an official at the activity to estimate the probable public affairs impact under these varying conditions by filling in Figure IV. He could estimate the impact and place a "good" or "bad" in each box assuming: (1) a spill is uncontained, (2) the liability incurred and (3) the method of boom employment utilized.

		Method of Boom Employment		
		I	II	III
An oil spill escapes to navigable water and the resulting liability incurred by the Navy is high, medium, or low for each of the three methods of boom employment.	High			
	Med.			
	Low			

Figure IV

C. DETERMINATION OF PARAMETER WEIGHTING USING DECISION ANALYSIS

1. Development of Scenarios with Varying Parameter Conditions

Figure V depicts six of the many possible scenarios for various parameter conditions. In each scenario the utility value will be different. In scenario one (1) all parameters are as desirable as possible and it has the

			Parameter Condition			
Scenario Number	Scenario Utility (U)	Liability (L)	Prob. of Uncontained Spill (P)	Cost ($)	Convenience (C)	Public Affairs (PA)
1	1.0	L_1	0	0	RC	G
2	UD	L_1	0	0	RC	B*
3	UD	L_1	0	0	IC*	G
4	UD	L_1	0	VH*	RC	G
5	UD	L_1	0.1*	0	RC	G
6	UD	L_h*	0	0	RC	G

where: UD = undetermined

L_1 = low liability potential

L_h = high liability potential

VH = very high dollar costs

RC = reasonably convenient

IC = inconvenient

G = good public affairs

B = bad public affairs

* = indicates the parameter driven to a worst case situation

Figure V

highest possible utility value, or 1.0. In scenario two (2) the parameter considered least important (PA) was driven to its worst case and in proceeding from scenarios two (2) through six (6) increasingly important parameters were driven to their worst cases (indicated by an asterisk). By doing this it may be deduced that the utilities of the scenarios will successively decrease. The decision maker must rank the relative importance of the parameters. For purposes of developing this plan the ranking chosen, in decreasing order of importance, was: (1) liability, (2) probability of an uncontained spill, (3) cost, (4) convenience and (5) public affairs.

2. Evaluation of Decision Forks (or Gambles)

A series of decision forks (or gambles) based on the scenarios developed above, will be evaluated in order to determine how much of one parameter's utility may be sacrificed in order to gain a certain amount of another parameter's utility. To do this an indifference percentage, or probability, (q), is determined for each gamble. The general form of these indifference gambles is shown in Figure VI.

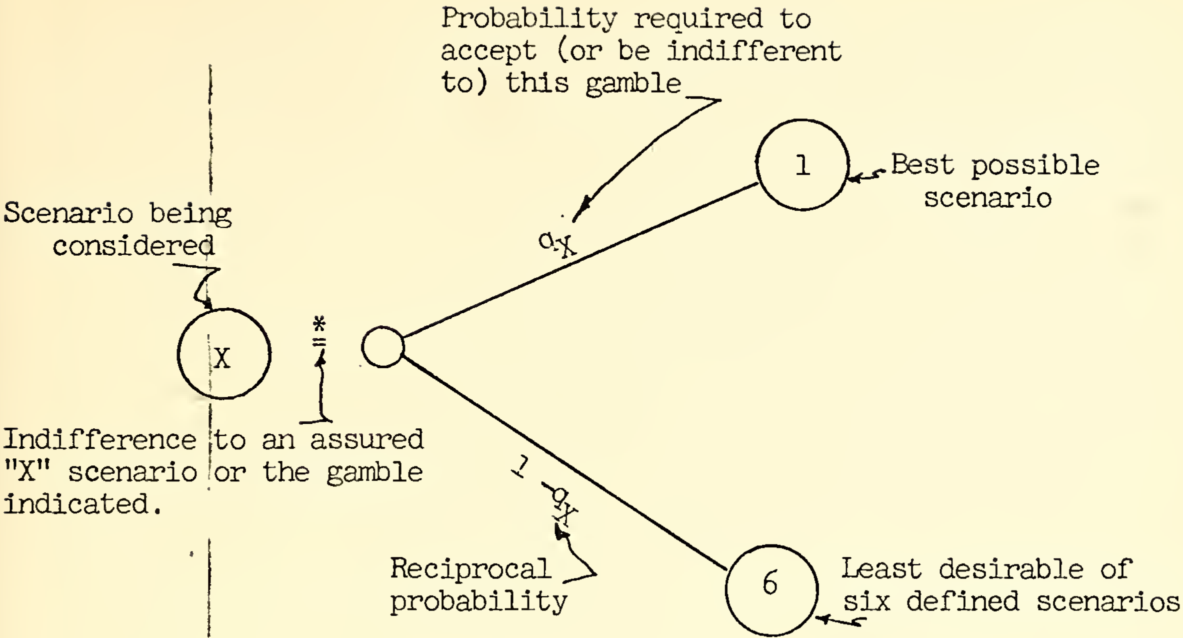
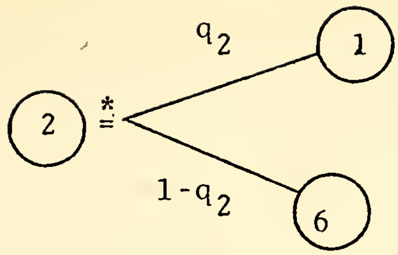


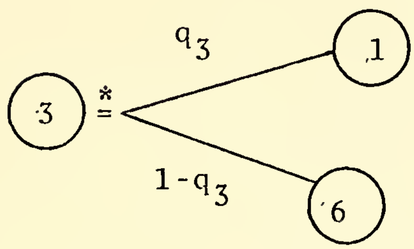
Figure VI

In each of the gambles selected for evaluation below, only two parameters are varied at a time since this is more easily conceptualized in the decision maker's mind. Varying more than two parameters at once may lead to erroneous or inconsistent determinations of acceptable probabilities. However, other scenarios and gambles may be developed to verify or test the probabilities determined. The gambles selected after several iterations and testing are indicated in Figures VII through X.



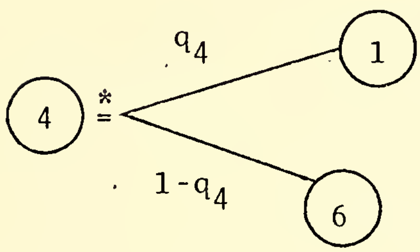
$q_2 = \underline{0.9}, \quad 1-q_2 = \underline{0.1}$

Figure VII



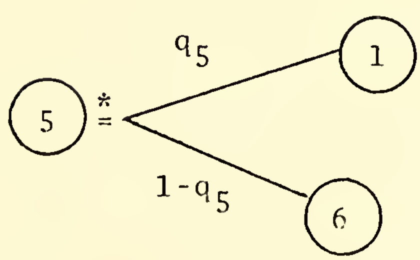
$q_3 = \underline{0.85}, \quad 1-q_3 = \underline{0.15}$

Figure VIII



$q_4 = \underline{0.5}, \quad 1-q_4 = \underline{0.5}$

Figure IX



$q_5 = \underline{0.2}, \quad 1-q_5 = \underline{0.8}$

Figure X

Using the gamble shown in Figure VII as an example, it can be seen that on one hand the outcome could be scenario two for certain (bad public affairs, but everything else is good). On the other hand, there is a gamble involving scenario one (everything good) with probability q, or scenario six (high liability, everything else good) with probability 1-q. Clearly, if q had a value of one the gamble would be preferable to scenario two. Also, if q had a value of zero, then scenario two would be preferable to the gamble. Thus, there must be some value of q between zero and one, such that scenario two and the gamble would be equally attractive. In this analysis that value was found to be $q = 0.9$.

3. Formulation of Simultaneous Equations

Following the format of equation (1), the utility of a given scenario in this problem may be expressed:

$$U_x = k_1u_1 + k_2u_2 + k_3u_3 + k_4u_4 + k_5u_5 \qquad (2)$$

where: U_x = utility of a scenario

$k_1 = k_L$ = weighting constant for the utility of liability potential

$u_1 = u_L$ = utility of liability potential

$k_2 = k_P$ = weighting constant for the utility of the probability of an uncontained spill

$u_2 = u_P$ = utility of the probability of an uncontained spill

$k_3 = k_\$$ = weighting constant for the utility of cost

$u_3 = u_\$$ = utility of cost

$k_4 = k_C$ = weighting constant for the utility of convenience

$u_4 = u_C$ = utility of convenience

$k_5 = k_{PA}$ = weighting constant for the utility of public affairs

$u_5 = u_{PA}$ = utility of public affairs

The utility of scenario one is a maximum value because all parameters, and their utilities, are optimized. This scenario utility is assigned a value of one.

$$U_1 = k_1u_1 + k_2u_2 + k_3u_3 + k_4u_4 + k_5u_5 = 1$$

Because the value of the utilities for all parameters was one, in scenario one, U_1 may be expressed simply as

$$U_1 = k_1 + k_2 + k_3 + k_5 = 1 \qquad (3)$$

In scenario two public affairs was reduced to its worst state so that its utility (u_{PA}) value becomes zero. The utility of scenario two is then

$$U_2 = k_1u_1 + k_2u_2 + k_3u_3 + k_4u_4 + k_5(0)$$

or

$$U_2 = k_1u_1 + k_2u_2 + k_3u_2 + k_4u_4$$

Because the value of the utilities for the first four parameters (u_1 through u_4) in scenario two was one, its utility may be expressed as

$$U_2 = k_1 + k_2 + k_3 + k_4$$

By substituting into equation (3)

$$U_1 = U_2 + k_5 = 1$$

or

$$U_2 = 1 - k_5 \qquad (4)$$

By performing similar substitutions for the utilities of scenarios three through six

$$U_3 = 1 - k_4 \qquad (5)$$

$$U_4 = 1 - k_3 \qquad (6)$$

$$U_5 = 1 - k_2 \qquad (7)$$

$$U_6 = 1 - k_1 \qquad (8)$$

5. <u>Solving for Weighting Constants</u>

Now using formulas (3) through (8), and the values q determined in the gambles in subparagraph IV.C.2 above, values of k_1 through k_5 can be determined.

$$U_2 = (q_2)U_1 + (1-q_2)\,U_6$$

$$1-k_5 = (.9)(1) + (.1)(1-k_1) = .9 + .1 - .1k_1 = 1 - .1k_1$$

$$k_5 = 0.1k_1 \qquad (9)$$

$$U_3 = (q_3)U_1 + (1-q_3)U_6$$

$$1-k_4 = (.85)(1) + (.15)(1-k_1) = .85 + .15 - .15k_1$$

$$= 1 - .15k_1$$

$$k_4 = 0.15k_1 \qquad (10)$$

$$U_4 = (q_4)U_1 + (1-q_4)U_6$$

$$1-k_3 = (.5)(1) + (.5)(1-k_1) = .5 + .5 - .5k_1 = 1 - .5k_1$$

$$k_3 = 0.5k_1 \tag{11}$$

$$U_5 = (q_5)U_1 + (1-q_5)U_6$$

$$1-k_2 = (.2)(1) + (.8)(1-k_1) = .2 + .8 - .8k_1 = 1 - .8k_1$$

$$k_2 = 0.8k_1 \tag{12}$$

Substituting equations (9) through (12) into equation (3) yeilds

$$k_1 + .8k_1 + .5k_1 + .15k_1 + .1k_1 = 1$$

$$2.55k_1 = 1$$

$$k_1 = .3922 \doteq .39$$
$$k_2 = .3138 \doteq .31$$
$$k_3 = .1961 \doteq .20$$
$$k_4 = .0588 \doteq .06$$
$$k_5 = .0392 \doteq .04$$

The weighted utility function for any scenario may then be expressed

$$U_x = .39u_1 + .31u_2 + .20u_3 + .06u_4 + .04u_5 \tag{13}$$

Figure XI is a summary of the ranking, weighting, symbology and utility range of the five parameters.

ORDINAL RANK	WEIGHT (k=)	NAME	SYMBOL	UTILITY SYMBOL	UTILITY VALUE RANGE	HARBOR DEPEN-DENT	METHOD DEPEN-DENT
1	0.39	Liabil-ity	L	u_L	0 or, 0.6 or, 1	Yes	No
2	0.31	Prob-ability Uncon-tained	P	u_P	See Figure I	Yes	Yes
3	0.20	Cost	$	$u_\$$	See Figure II	Yes	Yes
4	0.06	Conven-ience	C	u_C	1 or 0	Yes	Yes
5	0.04	Public Affairs	PA	u_{PA}	1 or 0	Yes	Yes

Figure XI

D. DETERMINATION OF UTILITY FOR EACH METHOD OF BOOM EMPLOYMENT

The utility for each method of boom employment may now be determined by obtaining information from the activity (using a questionnaire similar to that provided as Appendix C), computing the cost for each method (a sample is provided as Appendix E), determining the utility of each parameter using paragraph VI.B, filling in the decision tree provided in figure XII and performing the indicated computations. The weighting of the parameters is in accordance with formula (13).

LEGEND

aL_h: Probability of high liability

bL_m: Probability of medium liability

cL_l: Probability of low liability

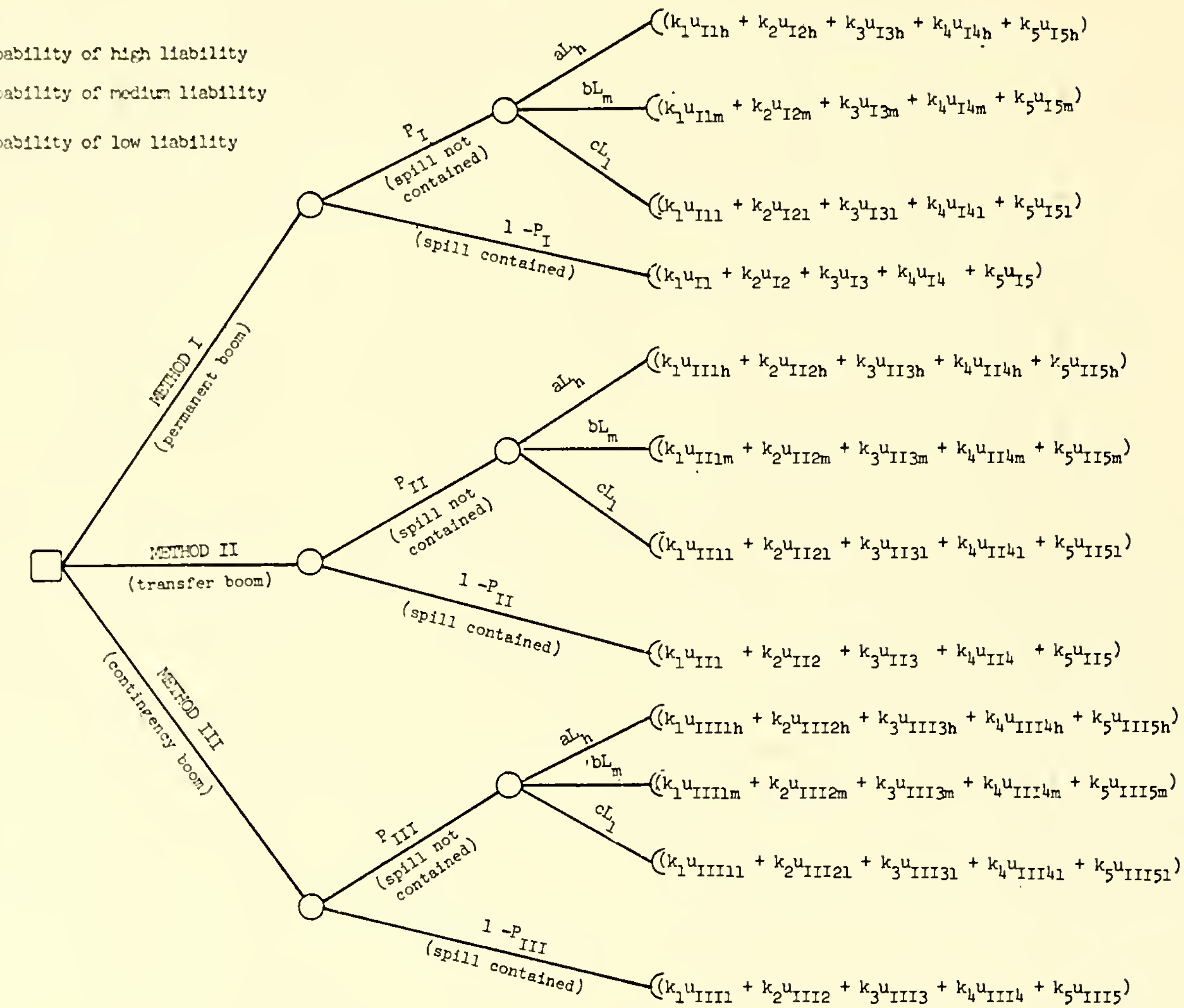


Figure XII

The factors in Figure XII are combined as indicated below.

Utility of Method I.

$$U_I = [(k_1u_{I1h} + k_2u_{I2h} + k_3u_{I3h} + k_4u_{I4h} + k_5u_{I5h})(aL_h)$$

$$+ (k_1u_{I1m} + k_2u_{I2m} + k_3u_{I3m} + k_4u_{I4m} + k_5u_{I5m})(bL_m)$$

$$+ (k_1u_{I1l} + k_2u_{I2l} + k_3u_{I3l} + k_4u_{I4l} + k_5u_{I5l})(cL_l)](P_I)$$

$$+ (k_1u_{I1} + k_2u_{I2} + k_3u_{I3} + k_4u_{I4} + k_5u_{I5})(1 - P_I)$$

Utility of Method II.

$$U_{II} = [(k_1u_{II1h} + k_2u_{II2h} + k_3u_{II3h} + k_4u_{II4h} + k_5u_{II5h})(aL_h)$$

$$+ (k_1u_{II1m} + k_2u_{II2m} + k_3u_{II3m} + k_4u_{II4m} + k_5u_{II5m})(bL_m)$$

$$+ (k_1u_{II1l} + k_2u_{II2l} + k_3u_{II3l} + k_4u_{II4l} + k_5u_{II5l})(cL_l)](P_{II})$$

$$+ (k_1u_{II1} + k_2u_{II2} + k_3u_{II3} + k_4u_{II4} + k_5u_{II5})(1 + P_{II})$$

Utility of Method III.

$$U_{III} = [(k_1u_{III1h} + k_2u_{III2h} + k_3u_{III3h} + k_4u_{III4h} + k_5u_{III5h})(aL_h)$$

$$+ (k_1u_{III1m} + k_2u_{III2m} + k_3u_{III3m} + k_4u_{III4m} + k_5u_{III5m})(bL_m)$$

$$+ (k_1u_{III1l} + k_2u_{III2l} + k_3u_{III3l} + k_4u_{III4l} + k_5u_{III5l})(cL_l)](P_{III})$$

$$+ (k_1u_{III1} + k_2u_{III2} + k_3u_{III3} + k_4u_{III4} + k_5u_{III5})(1 - P_{III})$$

The relative utilities of the three methods (U_I, U_{II} and U_{III}) can now be compared, and the decision maker may utilize this information as considered appropriate.

E. AN EXAMPLE OF DETERMINING THE UTILITY FOR EACH METHOD OF BOOM EMPLOYMENT AT: NAVAL AIR STATION, ALAMEDA

The numerical values to be filled in the decision tree are obtained from the questionnaire for NAS Alameda (Appendix D), the cost of oil spill containment at NAS Alameda (Appendix E), the value for parameter weighting constants from subparagraph IV.C.5, and the value of the utilities of the parameters from subparagraph IV.B. The actual numerical values for NAS Alameda are:

P_I: 0.01
P_{II}: 0.037
P_{III}: 0.10
$1-P_I$: 0.99
$1-P_{II}$: 0.963
$1-P_{III}$: 0.90
aL_h: 0.05
bL_m: 0.10
cL_1: 0.80
k_1: 0.39
k_2: 0.31
k_3: 0.20
k_4: 0.06
k_5: 0.04
u_{I1h}: 0
u_{I2h}: 0.98
u_{I3h}: 0.75
u_{I4h}: 1.0
u_{I5h}: 0

u_{I1m}: 0.6
u_{I2m}: 0.98
u_{I3m}: 0.75
u_{I4m}: 1.0
u_{I5m}: 0
u_{I11}: 1.0
u_{I21}: 0.98
u_{I31}: 0.75
u_{I41}: 1.0
u_{I51}: 1.0
u_{I1}: 1.0
u_{I2}: 0.98
u_{I3}: 0.75
u_{I4}: 1.0
u_{I5}: 1.0
u_{II1h}: 0
u_{II2h}: 0.93
u_{II3h}: 0.76
u_{II4h}: 1.0

u_{II5h}: 0
u_{II1m}: 0.6
u_{II2m}: 0.93
u_{II3m}: 0.76
u_{II4m}: 1.0
u_{II5m}: 0
u_{II11}: 1.0
u_{II21}: 0.93
u_{II31}: 0.76
U_{II41}: 1.0
u_{II51}: 1.0
u_{II1}: 1.0
u_{II2}: 0.93
u_{II3}: 0.76
u_{II4}: 1.0
u_{II5}: 1.0
u_{III1h}: 0
u_{III2h}: 0
u_{III3h}: 0.72

u_{III4h}: 1.0
u_{III5h}: 0
u_{III1m}: 0.6
u_{III2m}: 0
u_{III3m}: 0.72
u_{III4m}: 1.0
u_{III5m}: 0
u_{III11}: 1.0
u_{III21}: 0
u_{III31}: 0.72
u_{III41}: 1.0
u_{III51}: 0
u_{III1}: 1.0
u_{III2}: 0
u_{III3}: 0.72
u_{III4}: 1.0
u_{III5}: 1.0

These numerical values can now be inserted into a decision tree, as indicated in Figure XIII. The factors in Figure XIII are combined as indicated below:

Utility of Method I:

U_I = ((0 + .304 + .15 + .06 + 0)(.05) + (.234 + .304 + .15 + .06 + 0)(.15)

+ (.39+.304+.15+.06+.04)(.80)) (.01)+(.39+.304+.15+.06+.04)(.99)

= .9435

Utility of Method II;

U_{II} = ((0+.288+.152+.06+0)(.05)+(.234+.288+.152+.06-0)(.15)

+ (.39+.288+.152+.06+.04)(.80))(.037)+(.39+.288+.152

+.06+.04)(.963) = .9281

Utility of Method III:

U_{III} = ((0+0+.144+.06+0)(.05)+(.234+0+.144+.06+0)(.15)

+ (.39+0+.144+.06+0)(.80))(.10)+(.39+0+.144+.06+.04(.90)

= .6257

Method I has the highest utility (.9435) and will therefore provide the greatest effectiveness at NAS Alameda over a five year life cycle.

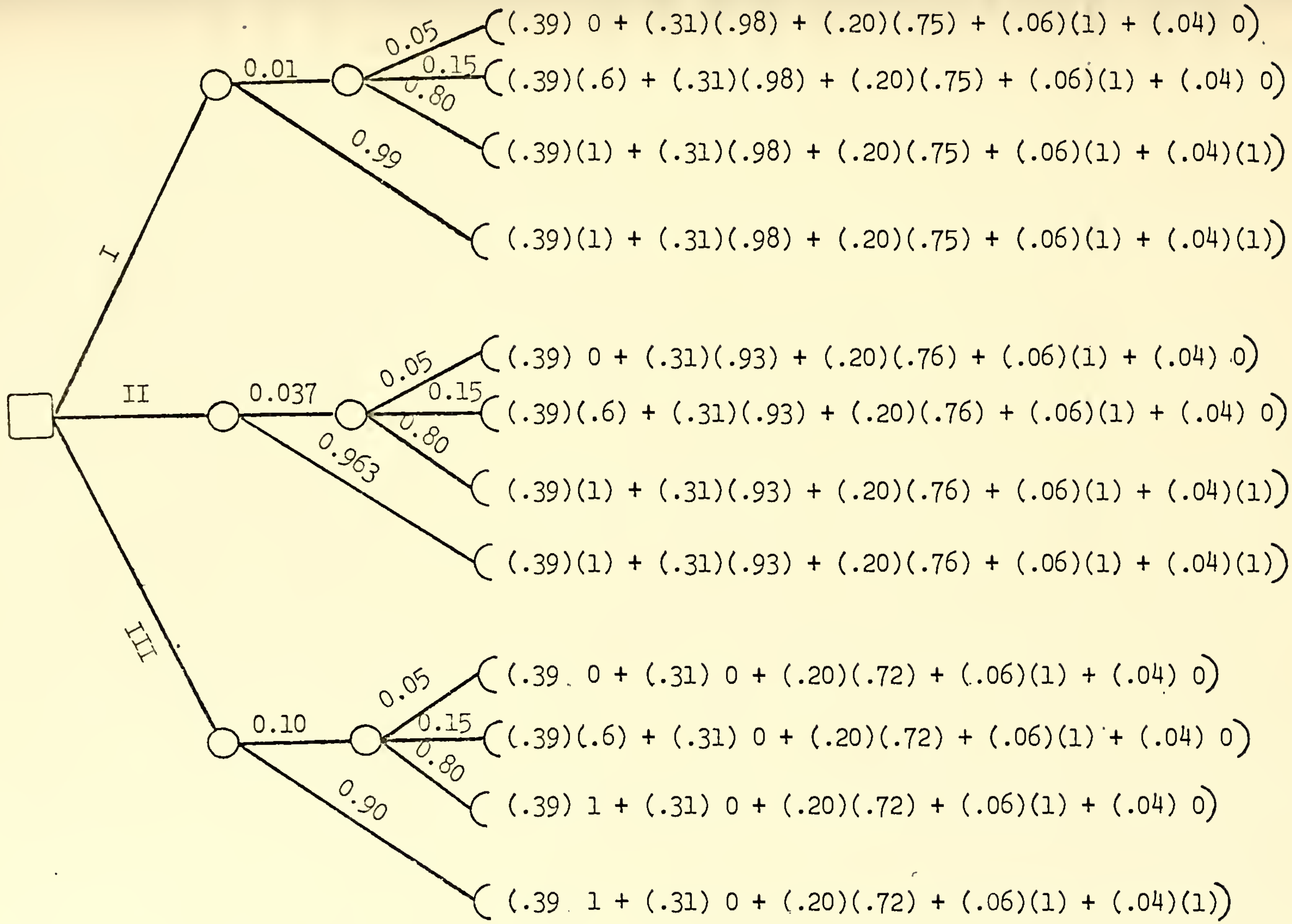

I
II
III
0.01
0.99
0.037
0.963
0.10
0.90
0.05
0.15
0.80
(.39) 0 + (.31)(.98) + (.20)(.75) + (.06)(1) + (.04) 0)
(.39)(.6) + (.31)(.98) + (.20)(.75) + (.06)(1) + (.04) 0)
(.39)(1) + (.31)(.98) + (.20)(.75) + (.06)(1) + (.04)(1))
(.39)(1) + (.31)(.98) + (.20)(.75) + (.06)(1) + (.04)(1))
(.39) 0 + (.31)(.93) + (.20)(.76) + (.06)(1) + (.04) 0)
(.39)(.6) + (.31)(.93) + (.20)(.76) + (.06)(1) + (.04) 0)
(.39)(1) + (.31)(.93) + (.20)(.76) + (.06)(1) + (.04)(1))
(.39)(1) + (.31)(.93) + (.20)(.76) + (.06)(1) + (.04)(1))
(.39 0 + (.31) 0 + (.20)(.72) + (.06)(1) + (.04) 0)
(.39)(.6) + (.31) 0 + (.20)(.72) + (.06)(1) + (.04) 0)
(.39) 1 + (.31) 0 + (.20)(.72) + (.06)(1) + (.04) 0)
(.39 1 + (.31) 0 + (.20)(.72) + (.06)(1) + (.04)(1))

Figure XIII

V. CONCLUSIONS

A plan has been formulated which will enable a decision maker to evaluate and rank three defined methods for deploying oil spill containment boom. The plan is based on a utility analysis of each method, using a decision analysis technique to determine the relative importance of various parameters effecting the utility of each method. Although these parameters are related, they are independent and can be considered individually. The plan identifies the data that must be obtained and demonstrates a method for organizing and manipulating the data. This plan can be of assistance to the decision maker in determining an optimum method for boom employment at each naval activity and then go on to determine containment device procurement requirements.

The research conducted provided assistance to the Civil Engineering Laboratory in its related efforts in support of the Naval Facilities Engineering Command. The research also uncovered an apparent discrepancy between the numbers of oil spills observed and the numbers reported to the Navy Environmental Support Office. A possible cost accounting problem was identified, in that oil spill cleanup costs are not specifically accumulated at the Navy's major claimant or Navy headquarters level.

There is a need for further study of the relative economy of procuring containment devices of varying costs and varying

expected life cycles. Further study could also be conducted to determine the possible economies that could be realized by employing commercial oil spill cleanup services, vice the utilization of Navy personnel, military or civilian, and equipment.

APPENDIX A

LINEAR REGRESSION ANALYSIS OF THE NUMBER OF NAVY OIL SPILLS FOR THE MONTHS OF 1972 AND 1973

Months 1972/1973	Month Number x	Number of Spills y	x^2	y^2	xy
JAN	1	68	1	4624	68
FEB	2	64	4	4096	128
MAR	3	54	9	2916	162
APR	4	32	16	1024	128
MAY	5	44	25	1936	220
JUN	6	43	36	1849	258
JUL	7	41	49	1681	287
AUG	8	38	64	1444	304
SEP	9	39	81	1521	351
OCT	10	35	100	1225	350
NOV	11	45	121	2025	495
DEC	12	24	144	576	288
JAN	13	30	169	900	390
FEB	14	34	196	1156	476
MAR	15	41	225	1681	615
APR	16	23	256	529	368
MAY	17	31	289	961	527
JUN	18	25	324	625	450
JUL	19	23	361	529	437
AUG	20	14	400	196	280
SEP	21	11	441	121	231
OCT	22	19	484	361	418
NOV	23	27	529	729	621
DEC	24	12	576	144	288
Σ	300	817	4,900	32,849	8,140

Linear Equation: $y = a + bx$

$\bar{x} = \frac{300}{24}$ $\underline{\underline{12.5}}$ $\qquad \bar{y} = \frac{817}{24} = \underline{\underline{34.04}}$

$S_{xx} = n\Sigma x^2 - [\Sigma x]^2 = 24(4,900) - (300)^2 = 117,600 - 90,000 = \underline{\underline{27,600}}$

$S_{yy} = n\Sigma y^2 - [\Sigma y]^2 = 24(32,849) - (817)^2 = 788,376 - 667,489 = \underline{\underline{120,887}}$

$S_{xy} = n\,\Sigma xy - [\Sigma x][\Sigma y] = 24(8,140) - (300)(817) = 195,360 - 245,100 = \underline{\underline{-49,740}}$

$$b = \frac{Sxy}{Sxx} = \frac{-49,740}{27,600} = \underline{\underline{-1.802}} \qquad a = \bar{y} - b\bar{x} = 34.04 - (-1.802)12.5 = \underline{\underline{56.57}}$$

Coefficient of Determination:

$$r^2 = \frac{[Sxy]^2}{Sxx\ Syy} = \frac{(-49,740)^2}{(27,600)(120,887)} = \underline{\underline{0.74152}}$$

Correlation Coefficient: $r = \underline{\underline{-0.8611}}$

$$\sigma_e \doteq Se = \left[\frac{Sxx\ Syy - (Sxy)^2}{n(n-2)\ Sxx}\right]^{\frac{1}{2}} = \left[\frac{(27,600)(120,887) - (-49,740)^2}{24(22)(27600)}\right]^{\frac{1}{2}}$$

Standard Deviation: $S_e = [59.18]^{\frac{1}{2}} = \underline{\underline{7.693}}$

CONFIDENCE INTERVALS (95%)

$$S_A = S_e \left[\frac{S_{xx} + [n\bar{x}]^2}{n\ (S_{xx})}\right]^{\frac{1}{2}} = 7.693 \left[\frac{27,600 + [(24)(12.5)]^2}{24\ (27,600)}\right]^{\frac{1}{2}} = \underline{\underline{3.239}}$$

$n = 24,\ n-2 = 22$

$t.025 \rightarrow 2.074$ (for 22 degrees of freedom)

$$a - (S_A)(t.025) \leq A \leq a + (S_A)(t.025)$$

$$56.57 - (3.239)(2.074) \leq A \leq 56.57 + (3.239)(2.074)$$

$$\underline{\underline{49.85 \leq A \leq 63.29}}$$

$$S_B = S_e \left[\frac{n}{S_{xx}}\right]^{\frac{1}{2}} = 0.227$$

$$b - (S_B)(t.025) \leq B \leq b + (S_B)(t.025)$$

$$-1.802 - (.227)(2.074) \leq B \leq -1.802 + (.227)(2.074)$$

$$\underline{\underline{-2.273 \leq B \leq -1.331}}$$

Significance Test for H_0: $B = 0$, or H_1: $B \neq 0$

$$t_B = \frac{b-B}{S_B} = \frac{-1.802-0}{0.227} = -7.938 = |7.938|$$

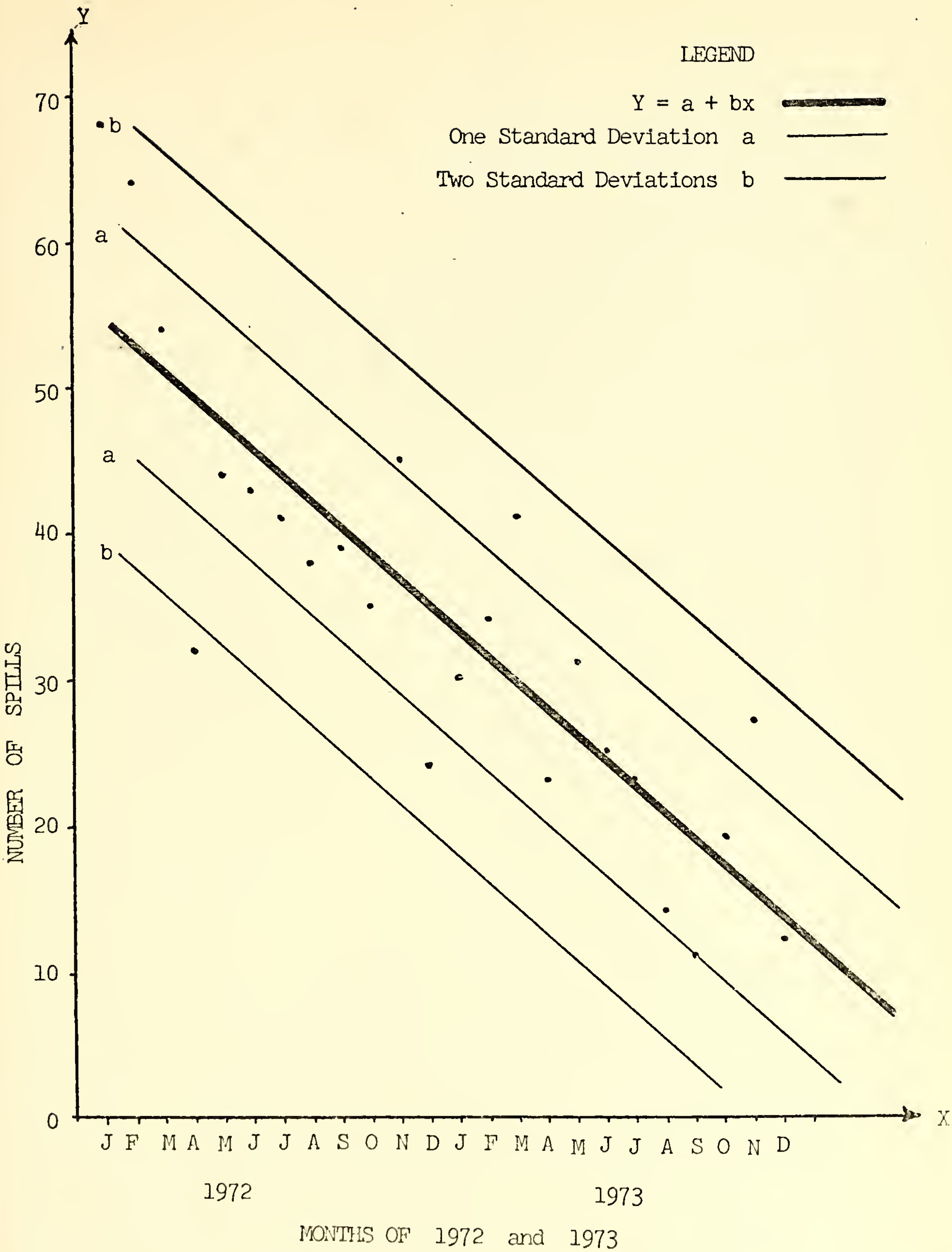
$t_{0.025} = 2.074$ for 22 deg. of freedom

Therefore, since $t_B > t_{.025}$, reject H_0 at 5% significance level.

RESIDUALS ANALYSIS

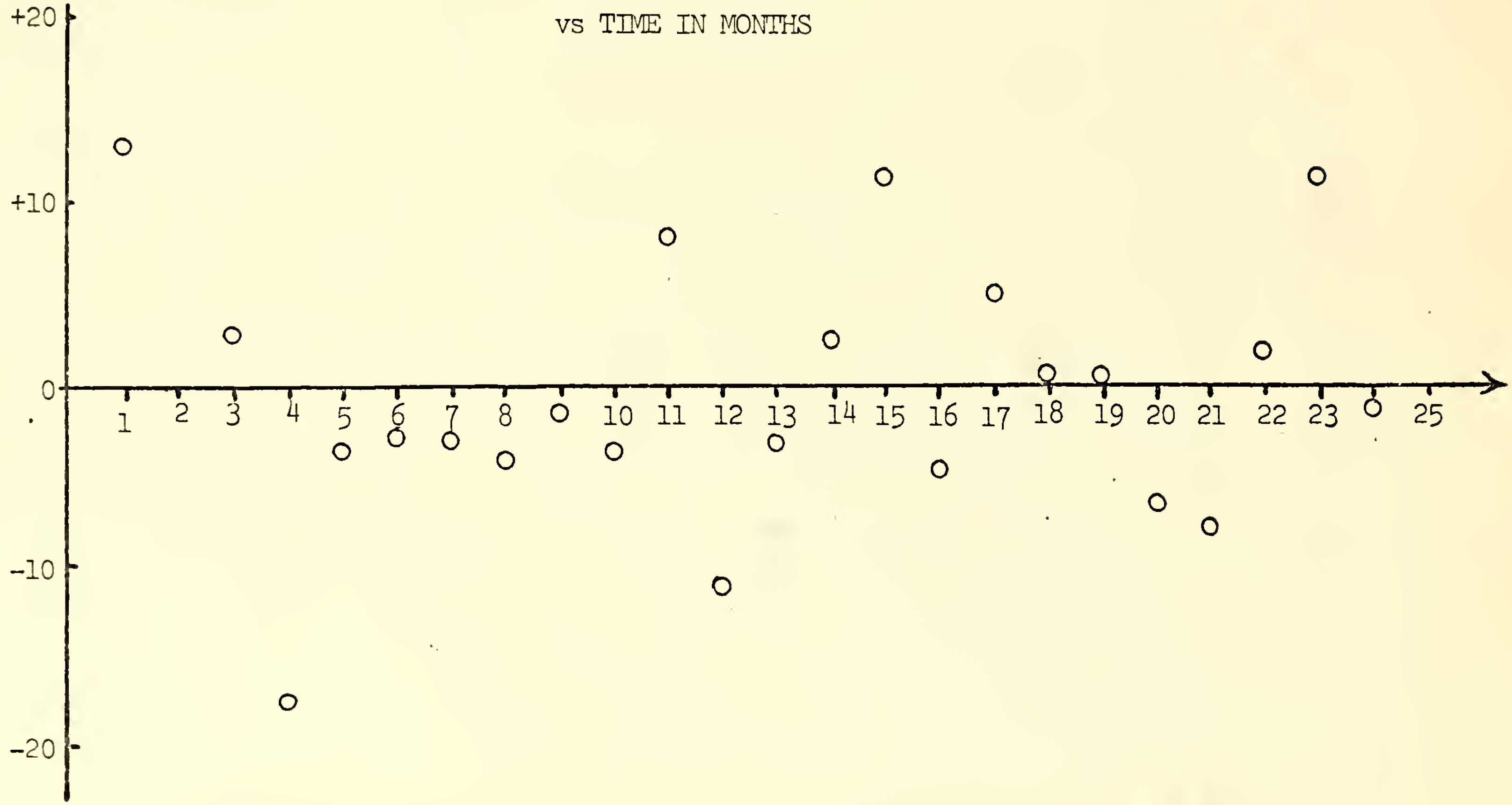
A Comparison of Predicted Number of Spills ($\overset{*}{y}$) With the Observed Number of Spills (y_i) [28]

1972/1973 x_i	Slope of Linear Equation b	bx_i	a	Number of Predicted Spills $\overset{*}{y}$	Number of Observed Spills y_i	Residual Value $y_i - \overset{*}{y}$
1	-1.802	- 1.802	56.51	54.71	68	13.29
2		- 3.60		52.91	64	11.09
3		- 5.40		51.11	54	2.89
4		- 7.21		49.30	32	-17.30
5		- 9.01		47.50	44	- 3.50
6		-10.81		45.70	43	- 2.70
7		-12.61		43.90	41	- 2.90
8		-14.42		42.09	38	- 4.09
9		-16.22		40.29	39	- 1.29
10		-18.02		38.49	35	- 3.49
11		-19.82		36.69	45	8.31
12		-21.62		34.89	24	-10.89
13		-23.43		33.08	30	- 3.08
14		-25.23		31.28	34	2.72
15		-27.03		29.48	41	11.52
16		-28.83		27.68	23	- 4.68
17		-30.63		25.88	31	5.12
18		-32.44		24.07	25	.93
19		-34.24		22.27	23	.73
20		-36.04		20.47	14	- 6.47
21		-37.84		18.67	11	- 7.67
22		-39.64		16.87	19	2.13
23		-41.45		15.06	27	11.94
24		-43.25		13.26	12	- 1.26



Y
LEGEND
Y = a + bx
One Standard Deviation a
Two Standard Deviations b
70
60
50
40
30
20
10
0
a
b
NUMBER OF SPILLS
X
J F M A M J J A S O N D J F M A M J J A S O N D
1972
1973
MONTHS OF 1972 and 1973

TIME SEQUENCE PLOT OF RESIDUALS:
ACTUAL NUMBER OF REPORTED SPILLS (y_i)
MINUS PREDICTED NUMBER OF SPILLS $(\overset{*}{y})$
vs TIME IN MONTHS



APPENDIX B

OIL SPILL CONTAINMENT FACT SHEET

The Civil Engineering Laboratory (CEL) has been tasked by NAVFAC to evaluate alternates to permanent oil containment booms at key Naval fuel stations. The purpose of this evaluation, being conducted in conjunction with a broader research program entitled, "Harbor Oil Spills Removal/ Recovery Systems", is to determine the relative economics of the various methods of utilizing containment boom. Responses will not be evaluated individually, but will be statistically compiled to obtain average or mean costs for the different classes of fuel stations and methods of boom use. From this investigation, parameters will be established and guidance crieria developed that will facilitate the cost effective selection and employment of containment boom at individual shore activities.

The data requested in this special fact sheet represent information not available in the Navy Environmental Protection Data Base also centered at CEL. Calendar years 1972 and/or 1973 should be used as base years for providing the requested data. Estimates may be made in instances where more accurate data is not available. Insert a check mark where appropriate for those questions offering a choice of answers. The fact sheet does not require typing. Questions concerning the information requested may be directed at Mr. Donald E. Brunner (CEL) telephone (Autovon) 360-4173 or (commercial) 805 982-4173. A reply is desired within the next thirty days. If questions asked cannot be completely answered within this time limit, partial replies will be acceptable.

The completed fact sheet should be returned in the enclosed pre addressed envelope to:

Officer-in-Charge
Civil Engineering Laboratory
Naval Construction Battalion Center
Environmental Protection Systems Division (L65)
Port Hueneme, CA 93043
ATT: Mr. D. Brunner

Choice of the person to respond to the fact sheet is the prerogative of the action addressee, but it would be desirable if that person had first hand experience in both the containment of oil spills and the costs involved.

Your cooperation is appreciated and will assist in the Navy's pollution control efforts.

OIL SPILL CONTAINMENT FACT SHEET

SECTION: I-GENERAL

1. Activity:

2. Address:

3. Activity classification:
   Bulk Fuel Depot ____________
   Large Naval Station, Shipyard, etc. ____________
   Small Naval Station, Shipyard, etc. ____________

4. Geographical description (include names of rivers, bays, etc. contiguous to ship's berthing area): ________________________________

   ____

   ____

5. Point of contact (Official in charge of oil spill containment/removal):

   a. Name: ________________________________

   b. Rank: ________________________________

   c. Title (e.g. Port Services Officer): ____________________

   d. Phone: ____________________

6. Pier description (Quay walls, wharfs, etc.) where fueling operations normally occur:

   a. Number of piers: ____________

   b. Total berthing capacity (linear feet): ____________________

   c. Average height of piers above mean low tide: ________, high tide: ______.

   d. Type construction (wooden piles, concrete, etc. Also indicate if piers are open or closed face (can water flow under/through pier)): ____________________________

   ____

   ____

7. Estimated annual fueling/defueling operations (include bulk fuel off loading):

Class Ship (CVA, DLG, DD, MSO, etc.)	Type Fuel (ND, NSFO, Diesel, etc.)	Number of Transfers per Year	Most Common Method of Transfer (from pier pipeline, barge, YOG, etc.)	Average Time Required for Transfer (or pumping rate)	Approximate Volume per Transfer

8. Pier loading (berth usage rate, expressed as a percentage of total linear footage of berthing capacity stated above in 6.b.):

a. Average: _______%

b. Normal Peaks: _______%

c. Percentage of berthing footage at which nesting of ships routinely occurs: ______%, average number of ships per nest: _______.

SECTION: II-ENVIRONMENTAL

9. Tides:

a. Type: Diurnal ________ Semidiurnal ________ Mixed __________

b. Mean Range (difference between high and low): ________________ ft.

c. Maximum Range: __________ft.

10. Currents:

a. Speed:

(1) Normal ________kts, Duration ___________hours.

(2) Maximum _______kts, Duration ___________hours.

b. Direction(s): ____

c. Cause(s): ____

d. Remarks or Rough Sketch (if desired/required):

11. Winds:

a. Speed: Average __________kts, Approximate percent of time ______%.

Peak ____________kts, Approximate percent of time ______%.

b. Prevailing direction from which wind blows ______________________.

c. Remarks:

12. Approximate Sea State:

a. Average: ____________ft.

b. Peak: _______________ft.

c. Remarks:

13. Normal observed pattern of spilled oil spreading (Do local conditions cause oil to spread in a common pattern/area? Does spilled oil tend to collect in a certain location? Etc. A rough sketch may be helpful):

14. Critical areas or facilities endangered in the event of a spill (wildlife area, recreation area, yatch harbor, park, etc.) A rough sketch if desired/required.

15. Unique circumstances or conditions that help or hinder oil spill containment cleanup operations:

SECTION: III-OIL SPILL CONTAINMENT EQUIPMENT

16. Present method(s) of deploying boom(s) in use at this activity:

a. Permanently positioned to contain spills or enclose berthing areas: ________.

b. Routinely positioned to encircle berthed ships: ____________.

c. Routinely positioned to encircle ships while transferring fuel: _____________.

d. Emergency deployment in event of spill: ___________________.

e. Combination of above: ______________.

f. Remarks:

17. Estimated linear footage of boom required for each of the above methods of boom deployment:

a. Permanently (16a): ____________________ft.

b. While ships berthed (16b): ____________________ft.

c. While ship transferring fuel (16c): ____________________ft.

d. In event of a spill (16d): ____________________ft.

18. Description of containment boom(s) presently owned and operated by the activity (Three colums provided in event more than one type boom is in use.):

	A	B	C
a. Trade Name			
b. Skirt depth (in)			
c. Freeboard height (in)			
d. Type Structural Material			
e. Structural Material Weight (lbs per linear foot)			
f. Type Flotation Material			
g. Total Boom Weight (lbs per linear foot)			

h: Total length (ft) ______ ______ ______

i. Cost per foot ______ ______ ______

j. Expected useful life (under present method of utilization) ______ ______ ______

k: Expected useful life if boom deployed (see 16 above) (in months)
   (1) Permanently---------------------______ ______ ______
   (2) While ships berthed-------------______ ______ ______
   (3) While ships transferring fuel---______ ______ ______
   (4) In event of a spill-------------______ ______ ______

l. Stowage location (in water, on pier, covered, in shed, on boat, etc.) ______ ______ ______

m. Type Stowage Container (if any) ______ ______ ______

n. Stowage Space Required (Cu. ft.) ______ ______ ______

o. Number of failures (disabling damages) per year of the following types; ______ ______ ______
   (1) Tears: ______ ______ ______
   (2) Loss of flotation: ______ ______ ______
   (3) Parting: ______ ______ ______
   (4) Other (Specify ________); ______ ______ ______
   (5) Other (Specify ________); ______ ______ ______

p. Number of failures per year from the following causes;
   (1) Structurally weak: ______ ______ ______
   (2) Debris in water: ______ ______ ______
   (3) Rough handling: ______ ______ ______
   (4) Poor design configuration: ______ ______ ______
   (5) Rough weather: ______ ______ ______
   (6) Other (Specify ________) ______ ______ ______

q. Total manhours required to repair failures: ______ ______ ______

r. Total annual labor costs to repair failures ($): ______ ______ ______

s. Total annual material costs to repair/replace failures: ______ ______ ______

t. Annual Preventitive Maintenance Costs:
   (1) Labor costs ______ ______ ______
   (2) Material costs ______ ______ ______
   (3) Total ______ ______ ______

u. Annual Stowage Costs (if any); ______ ______ ______

19. Costs to install booms if they are permanently deployed, or to pre-position booms in stowage location(s) if not permanently in water:

a. Manpower requirements/costs:

Type	Number of Personnel	Total Manhours	Total cost (if known)
Gov't Employee	________	________	________
Military	________	________	________
Contractor	________	________	________

b. Support equipment, services, material, contracts, etc.:

Item Description	Quantity	Unit Cost	Total Cost	Expected Useful Life (if applicable)

20. Containment boom operational costs:

a. Number of deployments (estimate if necessary):
   (1) Routine-----------------------------------1972______ 1973______
   (2) Emergency (in event of spill)------------1972______ 1973______

b. Time required to deploy boom (Hrs.) __________

c. Time required to retrieve and stow boom (Hrs.) __________

d. Estimated number of opening/closing cycles (to permit ship passage or other services/per deployment (average): __________

e. Total time required for opening/closing cycle (Hrs): __________

. Manpower requirements/costs:

Type	Per Deployment/Retrieval/Stowage			Per Open/Close Cycle		
	Number of Personnel	Total Manhours	Total Cost (if known)	No. of Personnel	Total Manhours	Total cost (if known)
Gov't Employee						
Military						
Contractor						

. Total support equipment, services, material, contracts, rentals, etc. required (Do not include those expeditures already accounted for in 19b. above):

Item Description	Expected Useful Life	Per Deployment/Retrieval		Per Open/Close Cycle	
		Quantity	Total Cost	Quantity	Total Cost

21. Navy owned oil pick-up equipment (skimmers, etc.). If this function was performed under a contract during 1972 or 1973, indicate annual cost and services that were performed:

Item Description	MFG Name & Mod. Nr.	Quantity	Useful Life (yr)	Total Cost

SECTION: IV-OIL SPILL DATA

22. Number of oil spills by ships, in various volume ranges and by type of fuel for CY-1972 and 1973. Also indicate the number of spills associated with an external fuel transfer (ship to pipeline, ship to barge etc.) and those associated with an internal fuel transfer. Pumping of bilges into a donut shall be considered an internal transfer. (If data is not available, estimates may be used, but estimates should be indicated by an *.): Include only spills involving ships while berthed at this activity:

a. 1972:

Type of Oil Spilled	Number of Spills per year, Classified by Volume of Spill															
	0 to 50 Gal		51 to 100 Gal		101 to 200 Gal		201 to 500 Gal		501 to 1000 Gal		1001 to 2000 Gal		2001 to 5000 Gal		Over 5000 Gal	
	Ext	Int	Ext	Int	Ext	Int	Ext	Int	Ext	Int	Ext	Int	Ext	Int	Ext	Int
ND																
NSFO																
Diesel																
Other (Specify):																

b. 1973:

Type of Oil Spilled	Number of Spills per year, Classified by Volume of Spill															
	0 to 50 Gal		51 to 100 Gal		101 to 200 Gal		201 to 500 Gal		501 to 1000 Gal		1001 to 2000 Gal		2001 to 5000 Gal		Over 5000 Gal	
	Ext	Int	Ext	Int	Ext	Int	Ext	Int	Ext	Int	Ext	Int	Ext	Int	Ext	Int
ND																
NSFO																
Diesel																
Other (Specify):																

23. Detailed oil spill and pick up data on not more than four spills during 1972/1973. If data is available on more than four spills, use one of the largest spills, one of the smallest, and two mid-range spills. For table columns concerned with oil pick up operations do not include requirements to deploy, retrieve or stow containment boom. If contractor services were used the total contractor charges may be shown and the extent of the services listed under remarks. (Estimates may be required for some of the data items, if so please indicate by an *.) Include only spills involving ships while berthed at this activity.

Type oil Spilled	Volume Spilled	Containment Method	Feet of Boom Used	Time from Spill until Containment	Spill Area	Oil Pick up Time	% of oil picked up	Number of Pick up Personnel			Number of Pick up Manhours			Cost of Consumable Material
								MIL	CS	CONT	MIL	CS	CONT	
1														
Remarks:														
2														
Remarks:														
3														
Remarks:														
4														
Remarks:														

APPENDIX C

<u>QUESTIONNAIRE TO PROVIDE DATA FOR A UTILITY ANALYSIS OF THREE METHODS FOR EMPLOYING OIL SPILL CONTAINMENT BOOM</u>

(Note: Some of this information will be: readily measurable/available, some will require that bids be made by contractors, minor computations may be required in some instances, and estimates by local personnel having the requisite cognizance will be required in other cases.)

ACTIVITY: ______________________________

1. Cost of oil spill containment.

   a. Procurement cost of permanent boom($/ft) __________

   b. Procurement cost of deployable boom($/ft) __________

   c. Procurement cost of ancillary equipment for permanent boom($/ft) ______________

   d. Procurement cost of ancillary equipment for deployable boom($/ft) ______________

   e. Installation costs of permanent boom($/ft) __________

   f. Linear feet of permanent boom required for each method of boom deployment:
      I ______________
      II ______________

   g. Linear feet of deployable boom required for each method of boom deployment:
      I ______________
      II ______________
      III ______________

   h. Number of times per year that boom would be opened/closed using: Method I ______________
      II ______________

   i. Man hours required to open/close boom using:
      Method I ______________
      Method II ______________
      Also indicate number of personnel required by military pay grade or G.S. level __________

   j. Tug/boat hours required to open/close boom using:
      Method I __________
      Method II __________

k. Man hour rate for operating boom using:
   Method I($/hr) ______________
   Method II($/hr) ______________

l. Operating rate per Tug/boat hour using:
   Method I($/hr) ______________
   Method II($/hr) ______________

m. Maintenance man days per year using:
   Method I ______________
   Method II ______________
   Method III ______________

n. Man day rate for maintenance($/day) ______________

o. Man days to clean boom per cleaning:
   Method I ______________
   Method II ______________
   Method III ______________

p. Man day rate for cleaning($/day) ______________

q. Number of times per year boom would have to be cleaned: Method I ______________
   Method II ______________
   Method III ______________

r. Number of times per year a spill occurs ______________
   (This prediction may be based on past history and any analysis technique considered appropriate (e.g. regression analysis) or simply an estimate.)

s. Man hours required to contain a spill using Method III ______________

t. Boat hours required to contain a spill using Method III ______________

u. Man hour rate to contain a spill using Method III($/hr) ______________

v. Boat rate to contain a spill using Method III($/hr) ______________

2. Costs of cleaning up an oil spill, exclusive of containment costs.

   a. Total cost of cleaning up spills each year using Method III ($) ______________

   b. Percent cleanup costs would be reduced if a spill is already contained, as would sometimes be the case using Methods I or II ($) ______________

3. Probability of a spill, once it occurs, entering navigable waters (P).

   a. Probability that a spill, once it occurs, will be contained if a boom is already in position (as in Method I) (%)________ = $\underline{s}$.

   b. Percentage of spills experienced, which occur during an external fuel transfer (%)________ = $\underline{r}$.

   c. Probability that a spill can be contained prior to entering navigable waters using Method III, or after it escapes Methods I or II (%)________ = $\underline{m}$.

   d. Probability of a spill entering navigable waters:

      (1) Method I: $P_I = (1-s)(1-m) =$ ________

      (2) Method II: $P_{II} = [(1-r) + r(1-s)](1-m) =$ ______

      (3) Method III: $P_{III} = (1-m) =$ ________

4. Convenience of methods, disregarding costs (check one for each method).

	Reasonably Convenient	Inconvenient
Method I	________	________
Method II	________	________
Method III	________	________

5. Probability of a spill, once it escapes containment, resulting in high, medium, and low damage:

   Probability of high damage (aL_h) ________

   Probability of medium damage (bL_m) ________

   Probability of low damage (cL_L) ________

   Total (must equal 1.0) 1.0

6. Public affairs impact of using different methods of boom employment and varying degrees of liability. Indicate "Good" or "Bad" in each of the nine blocks.

Method of Boom Employment

An oil spill escapes to navigable water and the resulting liability incurred by the Navy is high, medium or low for each of the three methods of boom employment		I	II	III
	High			
	Med.			
	Low			

APPENDIX D

UTILITY ANALYSIS DATA FOR NAVAL AIR STATION ALAMEDA

This appendix provides the data required to conduct a utility analysis of three methods for employing containment boom at Naval Air Station Alameda and is in the same format as the sample questionnaire provided in Appendix C.

This data was obtained by: conducting interviews with the Environmental Protection/Ecology Officer and Port Services Officer at NAS Alameda, contractor bids submitted to NAS Alameda for the installation of permanent boom, reviewing a report on a proposed oil spill containment system compiled by the Environmental Protection/Ecology Office of NAS Alameda, and personal observations. This data is used in compiling the cost of oil spill containment at NAS Alameda, Appendix E, and in the example of determining the utility of the three methods shown in paragraph IV.E of the basic study.

APPENDIX C

QUESTIONNAIRE TO PROVIDE DATA FOR A UTILITY ANALYSIS OF THREE METHODS FOR EMPLOYING OIL SPILL CONTAINMENT BOOM

(Note: Some of this information will be: readily measurable/available, some will require that bids be made by contractors, minor computations may be required in some instances, and estimates by local personnel having the requisite cognizance will be required in other cases.)

ACTIVITY: NAS Alameda

1. Cost of oil spill containment.

   a. Procurement cost of permanent boom($/ft) $20.00

   b. Procurement cost of deployable boom($/ft) $20.00

   c. Procurement cost of ancillary equipment for permanent boom($/ft) $1.64

   d. Procurement cost of ancillary equipment for deployable boom($/ft) $1.26

   e. Installation costs of permanent boom($/ft) $3.31

   f. Linear feet of permanent boom required for each method of boom deployment: I 4950
   II 0

   g. Linear feet of deployable boom required for each method of boom deployment: I 5300
   II 7500
   III 1800

   h. Number of times per year that boom would be opened/closed using: Method I 200
   II 50

   i. Man hours required to open/close boom using:
   Method I 2
   Method II 4
   Also indicate number of personnel required by military pay grade or G.S. level 1-E5, 1-E4, 2-E2

   j. Tug/boat hours required to open/close boom using:
   Method I 0.5
   Method II 1

k. Man hour rate for operating boom using:
Method I($/hr) $3.49 (1-F5, 1-F4, 2-E2 from NAVCOMPT
Method II($/hr) $3.49 Note 7041 of 20 Dec 1973)

l. Operating rate per Tug/boat hour using:
Method I($/hr) $10.00
Method II($/hr) $10.00

m. Maintenance man days per year using:
Method I 2
Method II 6
Method III 2

n. Man day rate for maintenance($/day) $30.00
(1-E4 from NAVCOMPT Note 7041 of 20 Dec 1973)

o. Man days to clean boom per cleaning:
Method I 205
Method II 150
Method III 30

p. Man day rate for cleaning($/day) $23.17
(1-E2 from NAVCOMPT Note 7041 of 20 Dec 1973)

q. Number of times per year boom would have to be cleaned:
Method I 4
Method II 4
Method III 2

r. Number of times per year a spill occurs 13
(This prediction may be based on past history and any analysis technique considered appropriate (e.g. regression analysis) or simply an estimate.)

s. Man hours required to contain a spill using Method III 194

t. Boat hours required to contain a spill using Method III 97

u. Man hour rate to contain a spill using Method III($/hr) $3.49

v. Boat rate to contain a spill using Method III($/hr) $10.00 per hour

2. Costs of cleaning up an oil spill, exclusive of containment costs.

a. Total cost of cleaning up spills each year using Method III ($) $138,252

b. Percent cleanup costs would be reduced if a spill is already contained, as would sometimes be the case using Methods I or II ($) 75

3. Probability of a spill, once it occurs, entering navigable waters (P).

   a. Probability that a spill, once it occurs, will be contained if a boom is already in position (as in Method I) (%) 0.90 = s.

   b. Percentage of spills experienced, which occur during an external fuel transfer (%) 70 = r.

   c. Probability that a spill can be contained prior to entering navigable waters using Method III, or after it escapes Methods I or II (%) .90 = m.

   d. Probability of a spill entering navigable waters:

      (1) Method I: $P_I = (1-s)(1-m) =$ 0.01

      (2) Method II: $P_{II} = [(1-r) + r(1-s)](1-m) =$ 0.37

      (3) Method III: $P_{III} = (1-m) =$ 0.1

4. Convenience of methods, disregarding costs (check one for each method).

	Reasonably Convenient	Inconvenient
Method I	X	
Method II	X	
Method III	X	

5. Probability of a spill, once it escapes containment, resulting in high, medium, and low damage:

Probability of high damage (aL_h)	.05
Probability of medium damage (bL_m)	.15
Probability of low damage (cL_L)	.80
Total (must equal 1.0)	1.0

6. Public affairs impact of using different methods of boom employment and varying degrees of liability. Indicate "Good" or "Bad" in each of the nine blocks.

An oil spill escapes to navigable water and the resulting liability incurred by the Navy is high, medium or low for each of the three methods of boom employment

	Method of Boom Employment I	II	III
High	Bad	Bad	Bad
Med.	Bad	Bad	Bad
Low	Good	Good	Bad

APPENDIX E

COST OF OIL SPILL CONTAINMENT AT: NAS ALAMEDA

These computations are based on the sample questionnaire filled out for NAS Alameda (Appendix D).

1. Method I

a. Boom procurement:

(1) Permanently installed boom, (Type I, Class 2, as defined by MILSPEC: MIL-B-28617(YD)).

linear feet times cost per foot
4950 x $20.00 = $ 99,000

(2) Deployable boom, (Type I, Class 2, as defined by MILSPEC: MIL-B-28617(YD))

linear feet times cost per foot
5300 x $20.00 = $106,000

$205,000

b. Ancillary Equipment:

(1) Permanently installed boom, (connection devices, anchors, hangers, shackles, etc.)

linear feet times cost per foot
4950 x $1.64 = $ 8,118

(2) Deployable boom, (connection devices, anchors, shackles, etc.)

linear feet times cost per foot
5300 x $1.26 = $ 6,678

$ 14,796

c. Installation of system, (labor, materials, related construction, etc.).

linear feet times cost per foot
10,250 x $3.31 = $ 39,928

d. Annual operating costs, (opening and closing booms, deploying boom along outboard sides of ship, etc.).

Number of open/close cycles per year times cost of one cycle

200 cycles per year
cost of one cycle:

2 Man hours x $3.49 = (4 men, in pay grades E-5, E-4 and two in pay grade E-2, working for 0.5 hours)	$6.98		
0.5 Boat hours x $10.00 =	$5.00		
	$11.98		
200 x $11.98 =			$ 2,396

e. Annual maintenance and cleaning costs.

(1) Maintenance: 2 man days x $30.00 per day = (pay grade E-4)		$ 60	
(2) Cleaning: 4 cleanings per year 205 man days per cleaning $23.17 per day (pay grade E-2)			
4 x 205 x $23.17 =		$ 19,000	
			$ 19,060

f. Annual contingency
Operating costs of containing spills escaping Method I deployment (permanent) by utilizing Method III (emergency).

Percent of spills escaping Method I times annual operating costs for Method III. (Note: Method III costs for procurement, maintenance and cleaning need not be added because deployable boom used for Method I could also be used in the Method III contingency).

0.01 x $21,412 =	$ 214
TOTAL FIRST YEAR COST FOR METHOD I	$281,394

2. Method II

a. Boom procurement (Type I, Class 2, as defined by MILSPEC: MIL-B-28617(YD))

linear feet times cost per foot
7500 x $20.00 = $150,000

b. Ancillary equipment (connection devices, anchors, shackles, etc.)

linear feet times cost per foot
7500 x $1.26 = $ 9,450

c. Installation: None

d. Annual operating costs, (deploying boom).

. Number of deployments per year times cost per deployment:

4 Man hours x $3.49 p/h = $13.96
(4 men, in pay grades E-5, E-4 and two in pay grade E-2 working for 1 hour)
1 Boat hour x $10.00 p/h = $10.00
$23.96

50 x $23.96 = $ 1,198

e. Annual maintenance and cleaning costs.

(1) Maintenance:
6 man days x $30 per day = $ 180

(2) Cleaning:
4 cleaning per year
150 man days per cleaning
$23.17 per day
(pay grade E-2)

4 x 150 x $23.17 = $ 13,902

$ 14,082

f. Annual, contingency, operating costs of containing spills escaping Method II deployment (transfer) by utilizing Method III (emergency).

Percent of spills occurring which are not cuased by an external transfer, plus percent of spills escaping Method II deployment (percent of spills caused by external transfer times percent of spills escaping Method II), times operating costs for Method III. (Note: Method III costs for procurement, maintenance and cleaning need not be added because deployable boom used for Method II could also be used in Method III contingency).

((0.30 + (.70)(.01))($21,412) =
(.307) x ($21,412) $ 7,922

TOTAL FIRST YEAR COST FOR METHOD II $182,652

3. Method III

a. Boom procurement (Type I, Class 2, as defined by MILSPEC: MIL-B-28617(YD)).

linear feet times cost per foot
1800 x $20.00 = $ 36,000

b. Ancillary equipment: None

c. Installation: None

d. Annual operating costs, (deploying boom and maintaining on station until spill is cleaned up).

spills per year times cost per spill
13 spills per year
194 Man hours x $3.49 p/h = $677.06
97 Boat hours x $10.00 p/h = 970.00
$1647.06

13 x $1647.06 = $ 21,412

e. Annual maintenance and cleaning

(1) Maintenance:
2 Man days x $30.00 p/d = $60
(pay grade E-4)

(2) Cleaning:
2 cleanings per year
30 man days per cleaning
$23.17 per day
(pay grade F-2)

2 x 30 x $23.17 = $1,390

$ 1,450

TOTAL FIRST YEAR COST FOR METHOD III $ 58,862

4. Comparison of First Year Containment Costs

Cost	Method I	Method II	Method III
Procurement	$205,000	$150,000	$ 36,000
Ancillary Equipment	14,796	9,450	---
Installation	39,928	---	---
Operation	2,396	1,198	21,412
Maintenance/Cleaning	19,060	14,082	1,450
Contingency Containment	214	7,922	---
TOTAL	$281,394	$182,652	$ 58,862

5. Comparison of Five Year Life Cycle Costs

Of the many booms available on the market some have guaranteed life of up to five years. These longer lasting booms cost in the range of $18.75 to $22.00 per foot, and a few of even higher cost. The lower priced booms in the range of $2.00 to $7.00 per foot have estimated lives of 30 to 90 days. It is readily apparent that the booms in the $20.00 per foot range will quickly pay for themselves, when compared to the less costly booms. Further, observation of the durability of the lower priced booms indicates that 30 to 90 days is an extremely optimistic estimate. None the less, we can compare the costs of the booms and see that more costly booms are more economical in a five year span.

5 Year Boom	90 Day Boom
Cost: $20.00	Cost: $2.00 - $7.00
Purchases required in 5 years: 1	Purchases required in 5 years: 20-60
5 Year Cost: $20.00	5 Year Cost:
	20 x $7.00 = $140.00
	60 x $2.00 = $120.00

A comparison of five year life cycle containment costs, considering booms in the $20.00 per foot range:

	Method		
Cost	I	II	III
Procurement	$205,000	$150,000	$ 36,000
Ancillary Equipment	14,796	9,450	---
Installation	39,928	---	---
Operation (x5)	11,980	5,990	107,060
Maintenance/Cleaning (x5)	95,300	70,410	7,250
Contingency Containment (x5)	1,070	39,610	---
TOTAL	$368,074	$275,460	$150,310

6. Comparison of Annual Costs on a Five Year Life Cycle Basis Cost

	Method		
Cost	I	II	III
Divide Five Year Life Cycle Costs by Five	$ 73,615	$ 55,092	$ 30,062

7. Present Value Costs for Five Year Life Cycle (using standard DOD ten percent mid-year discounting factors in accordance with DOD Instruction 7041.3)

Cost	Method I	Method II	Method III
Procurement	$205,000	$150,000	$ 36,000
Ancillary Equipment	14,796	9,450	---
Installation	39,928	---	---
Operation:			
Yr. 1	2,286	1,143	20,427
Yr. 2	2,077	1,039	18,564
Yr. 3	1,888	944	16,873
Yr. 4	1,718	859	15,352
Yr. 5	1,562	781	13,961
Maintenance/Cleaning:			
Yr. 1	18,183	13,434	1,383
Yr. 2	16,525	12,209	1,257
Yr. 3	15,019	11,097	1,143
Yr. 4	13,660	10,097	1,040
Yr. 5	12,427	9,181	945
Contingency Containment:			
Yr. 1	204	7,558	---
Yr. 2	186	6,868	---
Yr. 3	169	6,243	---
Yr. 4	153	5,680	---
Yr. 5	140	5,165	---
TOTAL	$345,921	$251,748	$126,945

8. Annual Oil Spill Cleanup Costs, Exclusive of Containment Costs

Spills which are already contained when they initially occur are much easier and less costly to cleanup. A prime Navy contractor who cleans up oil spills in the San Francisco Bay area, and who cleaned up all 13 of the oil spills experienced at NAS Alameda during 1973, claims that a contained spill can be cleaned up for about five percent of the cost of an uncontained spill. Because of this relative ease of cleanup, he will remove spills at no cost if a permanent

installation of his boom is employed and he is contracted to operate and maintain the boom. He has several contracts of this nature in effect and the second parties in these contracts claim that he has performed as advertised. In the event of a disastrously large spill he will incur cleanup costs up to $25,000 and any amount over that is paid by the second party in the contract. The important point is that he claims cleanup costs are reduced by 95% when the spills are contained by predeployed boom. Navy personnel experienced in cleaning up oil spills unanimously agree that a contained spill can generally be cleaned up for <u>less than half</u> (50%) the cost of an uncontained spill. A conservative figure of 75% will be used in this study to indicate the reduction in cleanup costs attributable to having containment boom predeployed.

a. <u>Method III</u>

Cost of cleaning up spills including containment cost, for the 13 spills experienced at NAS Alameda during 1973 (from contractor invoices):	$138,252
Annual containment cost using Method III, from paragraph 6 above:	30,062
Annual cleanup cost, exclusive of containment cost, using Method III:	$108,190

b. <u>Method I</u>

It has been estimated (Appendix D) that at least 0.9 of the spills experienced at NAS Alameda would be contained by predeployed boom. Therefore, cleanup costs for spills contained by predeployed boom = (0.9)(0.25) ($108,190):	$ 24,343

Cleanup costs of spills escaping predeployed boom = (0.1)($108,190): 10,819

Annual cleanup cost, exclusive of containment, using Method I: $ 35,162

c. Method II

It has been estimated (Appendix D) that 0.7 of the spills experienced at NAS Alameda occurred during experimental fuel transfers. Therefore, cleanup costs contained by predeployed boom, when Method II is employed = (0.7)(0.9)(0.25)($108,190): $ 17,040

Cleanup costs of spills not contained by predeployed boom when Method II is employed = [(0.3)+(0.7)(0.1)]($108,190) 40,030

$ 57,070

9. Comparison of Annual Cleanup Costs, Including Containment Cost

Cost	Method I	Method II	Method III
Containment Cost (from para. 6 above)	$ 73,615	$ 55,092	$ 30,062
Cleanup Cost (from para. 8 above)	35,162	57,070	108,190
TOTAL	$108,777	$112,162	$138,252

10. Present Value Five Year Life Cycle Cleanup Costs, Including Containment (using standard DOD ten percent mid-year discounting factors in accordance with DOD Instruction 7041.3)

Costs	Method I	Method II	Method III
Containment (from para. 7 above)	$345,921	$251,748	$126,945
Cleanup Costs, Exclusive of Containment Costs (from para. 8 above)			
Yr. 1	33,545	54,445	103,213
Yr. 2	30,485	49,480	93,801
Yr. 3	27,708	44,971	85,254
Yr. 4	25,211	40,919	77,572
Yr. 5	22,926	37,210	70,540
	$485,796	$478,773	$557,325

LIST OF REFERENCES

1. Gilman, B. C. (Ocean Systems, Inc.) Oil Spill Containment and Clean-Up Procedures, paper presented at conference on Environmental Design and Risk Criteria in Offshore Operations, San Francisco, California, 12-16 October 1970.

2. Navy Environmental Support Office Report 7-001, ACCIDENTAL OIL SPILLS-UPDATE REPORT-CY-72 and January through June 1973, p. II-4 to II-25, October 1973.

3. Navy Environmental Support Office Report 7-002, SUMMARY TABLES ON ACCIDENTAL OIL SPILLS 1973, p. 4-11, March 1974.

4. Wilson, J. E. (Naval Facilities Engineering Command), Harbor Spill Control, paper presented at Naval Ship Systems Command sponsored "Open Sea Oil Pollution Abatement" training course, Emeryville, California, 12 February 1974.

5. Naval Civil Engineering Laboratory, Naval Facilities Engineering Command Report Number CR.70.001, Study of Equipment and Methods for Removing Oil from Harbor Waters, by Battelle Memorial Institute, p. 4-1 to 4-73, 25 August 1969.

6. Department of Transportation, U.S. Coast Guard, Report 71386(R), Combating Pollution Created by Oil Spills, by Arthur D. Little, Inc., p. 17-93, 30 June 1969.

7. Linn, A., "From Civilization's Cradle to Europe's Cesspool," International Wildlife, v. 4, p. 4-11, March-April 1974.

8. Clawson, R. H., The Environmental Protection Agency, paper presented at Naval Ship Systems Command sponsored "Open Sea Oil Pollution Abatement" training course, Emeryville, California, 11 February 1974.

9. Public Law 92-500, Federal Water Pollution Control Act Ammendments of 1972, v. 86, p. 816-904, 18 October 1972.

10. Environmental Protection Agency, Proposed Criteria for Water Quality, Volume I, p. 290, October 1973.

11. Council on Environmental Quality, National Oil and Hazardous Substances Pollution Contingency Plan, Part 1510, Chapter V, Title 40, Code of Federal Regulations, 13 August 1973.

12. OPNAV INSTRUCTION 6240.3C, Environmental Protection and Enhancement Program; policy and assignment of responsibilities for, (CH-1), 20 April 1973.

13. NAVFAC INSTRUCTION 6240.2, Oil Spill Control Equipment Procurement Program, 6 April 1973.

14. NAVFAC NOTICE 6240, Oil Spill Equipment Procurement Program, 28 November 1973.

15. OPNAV NOTICE 6240, Oil Pollution Control Regulations for Non-transportation Related Onshore and Offshore Facilities, Enclosure: (1) Federal Register, Volume 38, No. 237, December 11, 1973, pgs. 34164-34169 "Non-transportation Related Onshore and Offshore Facilities, 13 February 1974.

16. Paulik, G. J., "Anchovies, Birds and Fishermen in the Peru Current," Environment, Resources, Pollution and Society, p. 156-185, Sinauer Associates, Inc., 1971.

17. Norton, R. W., Clean Bay Incorporated, paper presented at Naval Ship Systems Command sponsored "Open Sea Oil Pollution Abatement" training course, Emeryville, California, 12 February, 1974.

18. Blokker, P. C., Spreading and Evaporation of Petroleum Products on Water, paper presented at the Fourth International Harbor Conference, Antwerp, 22-27 June 1964.

19. Berridge, S. A., and others, "The Properties of Persistent Oils at Sea," Journal of the Institute of Petrol, v. 54, November 1968.

20. Schwartzberg, H. G., The Movement of Oil Spills, paper presented at American Petroleum Institute Conference on Prevention and Control of Oil Spills, Washington, D.C., 15-17 June 1971.

21. U.S. Coast Guard, Office of Research and Development Report Number 714102/A/008, Studies of Oil Retention Boom Hydrodynamics, by W. T. Lindenmuth, E. R. Miller and C. C. Hsu, p. 1-65, December 1970.

22. Abrahams, R. N. and Miller, F. R., Oil Spill Containment System Development and Testing Program, paper presented at American Petroleum Institute Conference on Prevention and Control of Oil Spills, Washington, D.C., 13-15 March 1973.

23. Wooten, D. C., Mechanical Control of Oil Spills Utilizing a Streamlined Boom, paper presented at American Petroleum Institute Conference on Prevention and Control of Oil Spills, Washington, D.C., 13-15 March 1973.

24. Military Specification, MIL-B-28617A(YD), Booms, Floating Barrier, Oil and Debris, 24 October 1973.

25. U.S. Navy Supervisor of Salvage, Study of Equipment and Methods for Removing or Dispersing Oil from Open Waters, by Battelle Pacific Northwest Laboratories, p. 7-26, August 1970.

26. Naval Civil Engineering Laboratory, Contract Number N62399-73-C-0026, Draft of final report on Evaluation of Oil Spill Recovery Systems in a Harbor Environment, by Battelle Columbus Laboratories, p. 7-16, 28 September 1973.

27. Naval Civil Engineering Laboratory, Report Number 211B01544, Draft of final report on Evaluation of Six Oil Containment Subsystems, by Battelle Pacific Northwest Laboratories, p. 1-25, October 1973.

28. Draper, N. R. and Smith, H., Applied Regression Analysis, p. 1-97, Wiley, 1966.

29. Quade, E. S. and Boucher, W. I., Systems Analysis and Policy Planning, American Elsevier, 1968.

30. Economic Analysis Handbook, Department of the U.S. Air Force, Office of the Comptroller.

31. Raiffa, H., Decision Analysis, Addison-Wesley, 1968.

32. Keeney, R. L., "Multiplicative Utility Functions," Operations Research, v. 22, p. 22-34, January-February 1974.

33. Tell, W. K., Summary of Laws and Regulations Governing Spills and Discharges of Oil, paper presented at American Petroleum Institute Conference on Prevention and Control of Oil Spills, Washington, D.C., 15-17 June 1971.

34. Wilkes, D., State Jurisdiction Over Oil Spills in a Federal System, paper presented at American Petroleum Institute Conference on Prevention and Control of Oil Spills, Washington, D.C., 15-17 June 1971.

35. Department of Defense Instruction 7041.3, Economic Analysis and Program Evaluation for Resource Management, 18 October 1972.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Department Chairman, Code 55 Department of Operations Research and Administrative Sciences Naval Postgraduate School Monterey, California 93940	1
4.	Professor J. W. Creighton, Code 55Cf Department of Operations Research and Administrative Sciences Naval Postgraduate School Monterey, California 93940	5
5.	Assistant Professor W. C. Giauque, Code 55Gi Department of Operations Research and Administrative Sciences Naval Postgraduate School Monterey, California 93940	1
6.	Associate Professor M. U. Thomas, Code 55To Department of Operations Research and Administrative Sciences Naval Postgraduate School Monterey, California 93940	1
7.	Associate Professor C. F. Rowell, Code 61Rw Department of Physics and Chemistry Naval Postgraduate School Monterey, California 93940	1
8.	CDR J. J. Larson, USN USS PLYMOUTH ROCK (LSD 29) c/o Fleet Post Office New York, N.Y. 09501	2
9.	Mr. Donald Brunner, Code L65 Civil Engineering Laboratory Naval Construction Battalion Center Port Hueneme, California 93043	1

10. Library 1
Civil Engineering Laboratory
Naval Construction Battalion Center
Port Hueneme, California 93043

11. Mr. S. M. Hurley 1
Code: FAC 032B
Naval Facilities Engineering Command
200 Stovall Street
Alexandria, Virginia 22332

12. Mr. Robert Salazar 1
Code: ON
U.S. Naval Air Station
Alameda, California 94101

13. CAPT Joseph D'Emidio, CEC, USN 1
OP45
Director of Environmental Protection
Division
Pentagon Building, RM 4B516
Washington, D.C. 20350

14. LCDR W. P. McTomney, CEC, USN 1
Director, Navy Environmental Support
Office
Civil Engineering Laboratory
Naval Construction Battalion Center
Port Hueneme, California 93043

15. CDR R. D. Fasig, USN 1
Pollution Control Officer
Staff, Eleventh Naval District
San Diego, California 92132

16. LCDR Robert Armacost, USCG 1
USCG Headquarters
400 7th Street, S.W.
Washington, D. C. 20591

152691
Thesis
L2735 Larson
c.1
An examintation of alternative methods for employing booms to contain oil spills in Navy harbors.